ISIS

INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

Know Your Car

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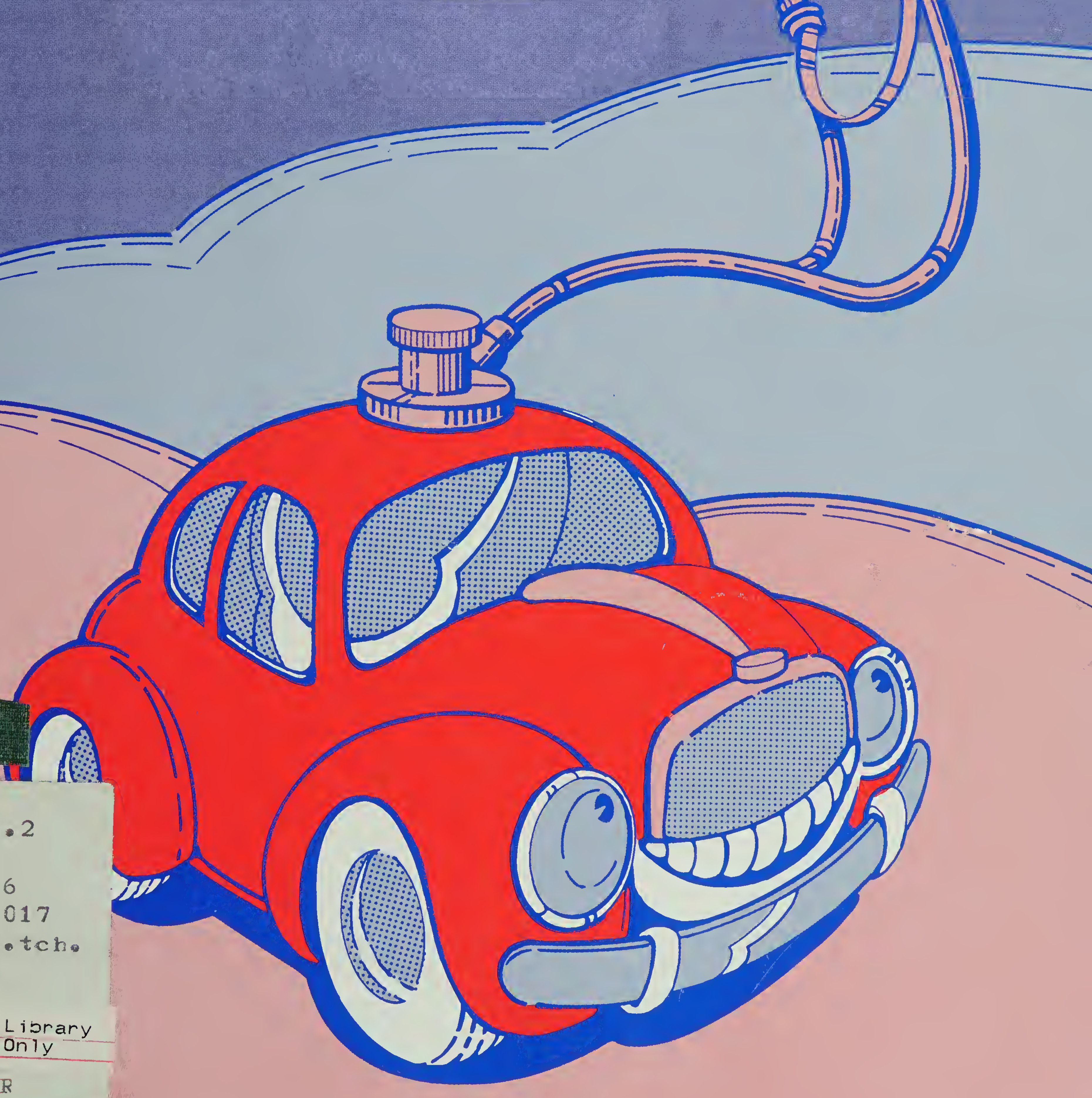

ISIS

INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

Know Your Car

ANNOTATED TEACHER'S EDITION

Ginn and Company

This is a publication of the Individualized Science Instructional System conducted by The Florida State University Educational Research Institute and supported by a grant from the National Science Foundation. The opinions expressed herein do not necessarily reflect the position or policy of the National Science Foundation, and no official endorsement by that agency should be inferred.

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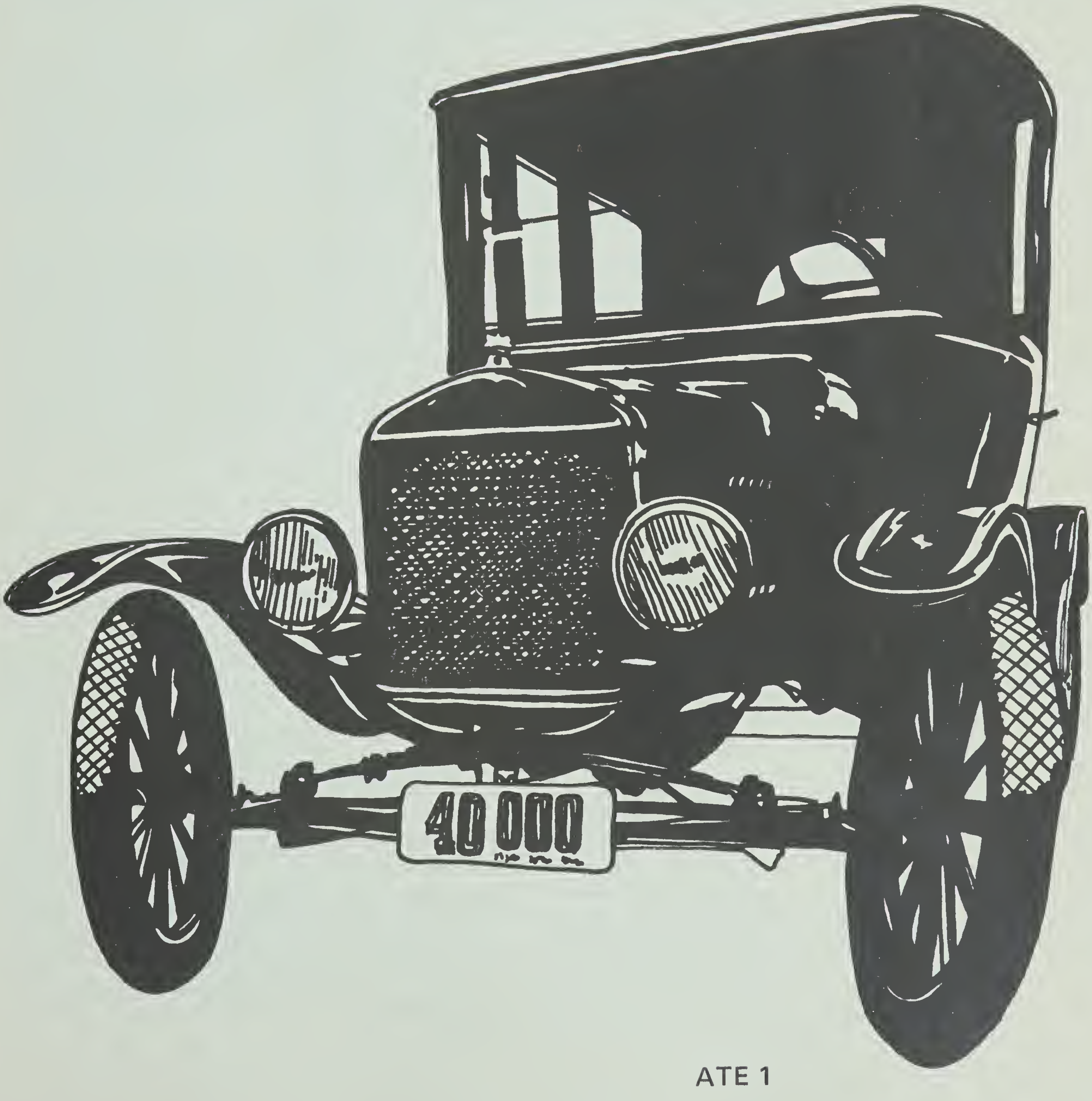
CONTENTS	ATE PAGE



OVERVIEW

The topic of the car can serve as strong motivation for your students, many of whom are beginning drivers. Choosing a car may be a big decision in their near future, probably the first major expense and responsibility in their lives.

Many students know very little about the automobile, and even less about the physical principles underlying its operation. Although a few of your students may already know more about the car than five minicourses could teach, they, too, probably know little of the background science. *Know Your Car* will not make a mechanic of anyone, nor is it intended as a comprehensive owner's manual. But it will maintain interest while providing basic scientific knowledge.

ORGANIZATION

This minicourse contains eight core activities, five advanced activities, and three excursion activities. The first activity in each section is a planning activity, which should be done before any of the other activities. If students plan to do Activity 2, they should do it right after Activity 1. The other activities may be done in any order.

Almost every core activity focuses on a different subsystem of the car; the ignition, cooling, fuel, lubrication, and tire systems all are explained. Each activity makes an effort to provide simple maintenance or repair tips for the system it describes.

Advanced activities delve into some basic physics exemplified by the operation of the cooling system (expansion and contraction), steering and braking (static versus kinetic friction), and the diesel engine (kinetic molecular theory). One activity uses the suspension system as an entry to Hooke's law.

One excursion looks at exhaust systems from the viewpoint of pollution and how it can be lessened. The other gives information about power, displacement, and compression ratio.

MATERIALS AND EQUIPMENT

The following tables show the quantity and the frequency of use of each item used in each activity. The activities that require no materials are not listed in the tables.

It is important to collect and organize all the materials for each minicourse before the students begin any of the activities, since the students will be working simultaneously on different activities. Having all materials readily available allows students to do the activities in the order they choose. The amount of material you will need to make available will depend on the number of lab groups that will be doing each activity. As lab groups use the "skipping option" and as they scatter themselves throughout the activities, the total amount of materials needed at one time for each activity will decrease.

NONCONSUMABLE ITEMS	MINIMUM MATERIALS PER LAB GROUP† PER ACTIVITY											
	2	3	4	5	6	7	8	10	11	12	13	15
*Ball, steel, 14.3 mm diameter									1			
Ball, table tennis											1	
Beaker, 50 ml, or jar		2			1							
Beaker, 100 ml, or jar				1								
*Block, wood, about 10 cm X 7 cm X 2 cm										1		
Board, wood, about 100 cm X 15 cm X 2 cm										1		
Book, hardcover											1	
Bulb, flashlight, 2.5 V, with socket	1	1										
Burner, Bunsen, or alcohol				1					1			
Capacitor (condenser), auto or lawn mower			1									
Clamp, utility				1				1				
Coil, induction, automobile			1									
Dropper nozzle					1							
Dry cell, 1.5 V	1											
*Hook, cup										1		
*Mass, 100 g								6				
Mass, 500 g										1		
*Material, rough, 50 cm X 15 cm										1		
*Material, smooth, 50 cm X 15 cm										1		
Metre stick											1	
Pad, asbestos									1			
*Pan, metal	1											
*Power supply, or battery, 4-6 volt DC		1										
Power supply, or battery, 6-12 volt DC			1									
*Radiator assembly consisting of				1								
flask, 250 ml				1								
stopper, 1 hole, to fit flask				1								
tubing, glass (cm)				30								
tubing, rubber or plastic (cm)				40								
Razor blade or craft knife					1							
Ring stand				1				1				
Rubber band							1					
Ruler, metric							1	1				
Safety goggles		1		1					1			1
Scale, spring, calibrated in newtons										1		
Screwdriver, heavy						1						
Spark plug, auto or lawn mower			1									
*Spring, helical, steel, about 10 cm long								1				
Switch, knife, single pole, single throw	1		1									
Test tube with cork												1
Test-tube holder or tongs									1			1
*Washer, aluminum, 14.3 mm inside diameter									1			
Watch or clock, with second hand		1										
*Wire lead, with 2 clips	4	2	7									

*See "Advance Preparations."

†A *lab group* is defined as one student, a pair of students, or any size group of students that you choose.

NONCONSUMABLE ITEMS	MINIMUM MATERIALS PER LAB GROUP† PER ACTIVITY											
	2	3	4	5	6	7	8	10	11	12	13	15
Resource Unit 4								1				
Resource Unit 6							1					
Resource Unit 9							1					
Resource Unit 13				1								

*See "Advance Preparations."
†A *lab group* is defined as one student, a pair of students, or any size group of students that you choose.

CONSUMABLE ITEMS	MINIMUM MATERIALS PER LAB GROUP† PER ACTIVITY							
	2	3	5	6	7	10	11	15
Candle								1
*Cardboard, 3.5 cm X 7 cm		2						
*Lead foil, 3 cm X 6 cm piece		2						
*Limewater (ml)								10
Match, safety			2				2	2
*Oil, special, STP or equivalent (ml)					1			
Steel wool pad		1						
Straw, drinking, plastic				1				
*Sulfuric acid, 0.5M (ml)		40						
Tape, plastic or masking (cm)	4					20		
Towel, paper					4			

*See "Advance Preparations."
†A *lab group* is defined as one student, a pair of students, or any size group of students that you choose.

ADVANCE PREPARATIONS

General

Activities 2, 3, and 4 call for wire to be used to connect various components in a circuit. The procedure can be greatly simplified for the student if test leads with alligator clips on the ends, such as the lead shown below, are furnished. A more positive connection can be made, no screwdriver is necessary, and the leads can be used again and again.

If such leads are provided, the student will not need the tape for Activity 2, called for in the "Consumable Items" table above.

Activity 2

The pan, which serves as a model for the frame of a car, should be metal or metal covered. Aluminum foil over a plastic tray

would do the job. If a metal pan is used, be sure the metal is shiny on the ends where connections are made.

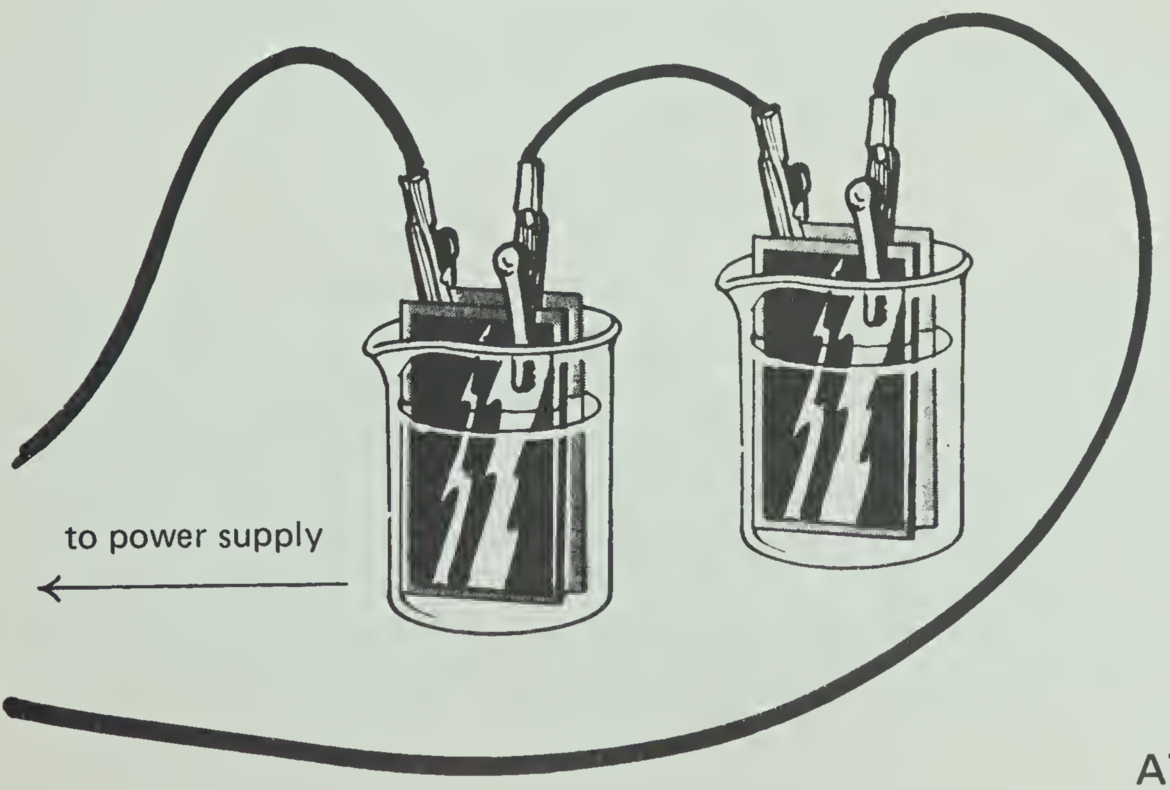
Activity 3

Sulfuric acid, 0.5M, H_2SO_4. Slowly add 14 ml of concentrated H_2SO_4, 17.8M, or 95%, to 500 ml of water. Caution: Always add acid to water, never the reverse. See *Managing ISIS* for general instructions on the safe use and disposal of chemicals. Remember that sulfuric acid is highly corrosive, and encourage your students to handle it carefully. However, a 0.5M solution is safe enough for students to use if reasonable care is taken.

The cardboard pieces are specified as 3.5 cm wide so that they will fit into a 50-ml beaker. If a different size container is used for making the battery, the width can be adjusted accordingly. The lead foil, specified at 3 cm X 6 cm, can likewise be any size that doesn't exceed that of the cardboard. The lead foil may be any thickness, from thin lead foil to thick flashing used in building. Incidentally, although listed as consumable, the lead may be reused if care is taken in cleaning it. The brown coating can be removed by soaking the strips in vinegar, which is a 5% acetic acid solution.

The power supply can either be a battery or a battery charger. Each of the little lead cells develops 2 volts, so you need at least 3 volts to charge them properly. If a 6-volt power supply or battery is used, two cells could be charged at the same time, hooked in series, as shown below. With a 12-volt supply, four could be in series.

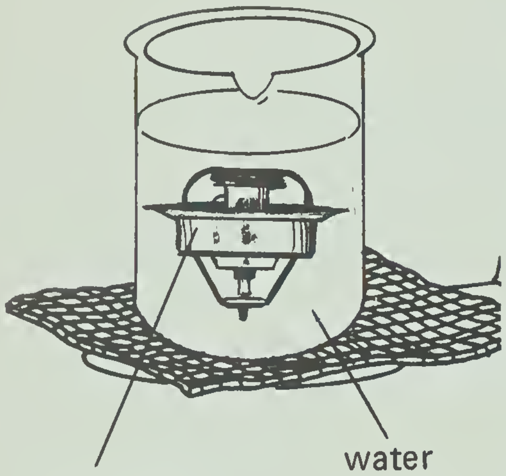
two cells in series



Activity 4

The spark plug, coil, and capacitor (condenser) may be purchased new or reconditioned. Perhaps your shop or automotive teacher can lend you the parts and try them out for you. A car's distributor can be substituted for the knife switch to add more realism. It may even have a built-in capacitor.

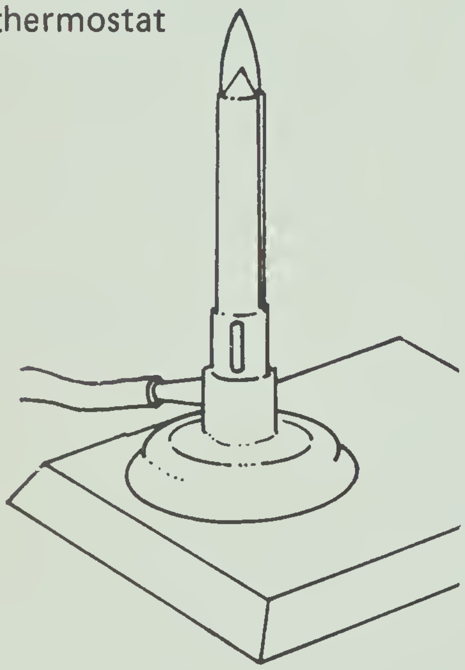
Activity 5



You may want to set up the radiator overflow system ahead of time and leave it assembled for each succeeding student or group to use. It will save wear and tear on the apparatus and eliminate the necessity for students to insert the glass tubing into the stopper and rubber tubing, which is a potentially dangerous operation.

You might want to add a little food coloring to the beaker. When the liquid is drawn back into the flask, it is more dramatic.

On page 29, the suggestion is made that if an automobile thermostat is available, the student could put it in hot and cold water to observe its operation. Thermostats are available from junkyards, but even new, the cost is nominal, and heating and cooling one in a glass beaker is a simple yet very observable procedure.



Activity 7

The special oil used with the screwdriver should be STP oil treatment additive or its equivalent. The oil can be poured from the can into a large-mouth jar or beaker, and, as far as the students are concerned, can be treated as regular lubricating oil. The special oil can be very messy. Use care.

Activity 10

The equipment list calls for six 100-g masses. It is not necessary to have these as long as you have six objects of equal weight that can be hung on the spring. The 100 g gives a downward force of gravity of close to 1 newton, which is a convenient size unit for the investigation and the resulting graph. One solution, if you don't have the 100-g masses that can be hung, is to hang a pan on the spring. Then, equal masses can be added to the pan. The newtons of weight can be determined by weighing them on the spring scale used in Activity 12.

Physics teachers may have a Hooke's law apparatus that you can use. It should consist of a ruler and stand with the proper sizes of spring and weights.

Activity 11

A commercial ball and ring can be used in place of the washer and steel ball. In that case, students can follow this procedure.

1. Heat the ball until it won't go through the ring.
2. Then heat the ring.
3. Prove that the ball will again go through the ring.

By following these steps, the students can still see that the ring expands when heated and that the inner hole becomes larger.

Activity 12

Screw the cup hook into one end of the wooden block. You may wish to bend the cup hook to form an eyelet before screwing it into the block. Possibly, the wooden board and block may be borrowed from your school's shop class.

Toward the end of the activity, materials with a rough surface and with a smooth surface are called for. You can use any convenient material at hand. Most loose-textured cloths would do for the rough, as would carpet or rough cardboard. Sandpaper fastened to a board would work well. Plastic as is used on counter tops would be excellent for the smooth surface, and you may be able to get a scrap piece. A strip of tempered masonite works very well. One side is smooth, the other side textured.

Activity 15

Limewater. Put 5 grams (about a teaspoonful) of calcium hydroxide into a 1-litre container. (A plastic quart milk container will do.) Add 1 litre of tap water. Stopper the container, and shake it vigorously. Let the container stand overnight. The undissolved solid will settle to the bottom. Carefully pour the clear limewater into another storage bottle for use. The undissolved solid can be discarded in the sink.

BACKGROUND INFORMATION

Friction

Friction, dealt with in three different activities of this mini-course, is the constant foe of most machinery. One helpful manifestation of friction is its role in traction.

In anticipation of some questions from students, consider these five principles.

1. Frictional force is proportional to the force that presses the two surfaces together. So, if tire contact area with the road is constant, a heavier car will have more traction than a lighter car.

2. Frictional force acts parallel to the surfaces in contact. When overcoming friction, the best application of the opposing force should be parallel to the surfaces also. Pushing down increases friction. Pushing up works against gravity.

3. Frictional force is roughly independent of both the speed of sliding and the areas of the surfaces in contact. A car's stopping distance at 100 km/h is more than twice what it is at 50 km/h. This is due to the increased kinetic energy of the car, $KE = \frac{1}{2} mv^2$ (note that increased velocity is squared, not doubled), not to a change in friction. Likewise, a greater contact area, as with a wider tire, does not guarantee increased friction. But it does help assure that the tire will have a greater chance of contacting a dry, nonslippery portion of the road.

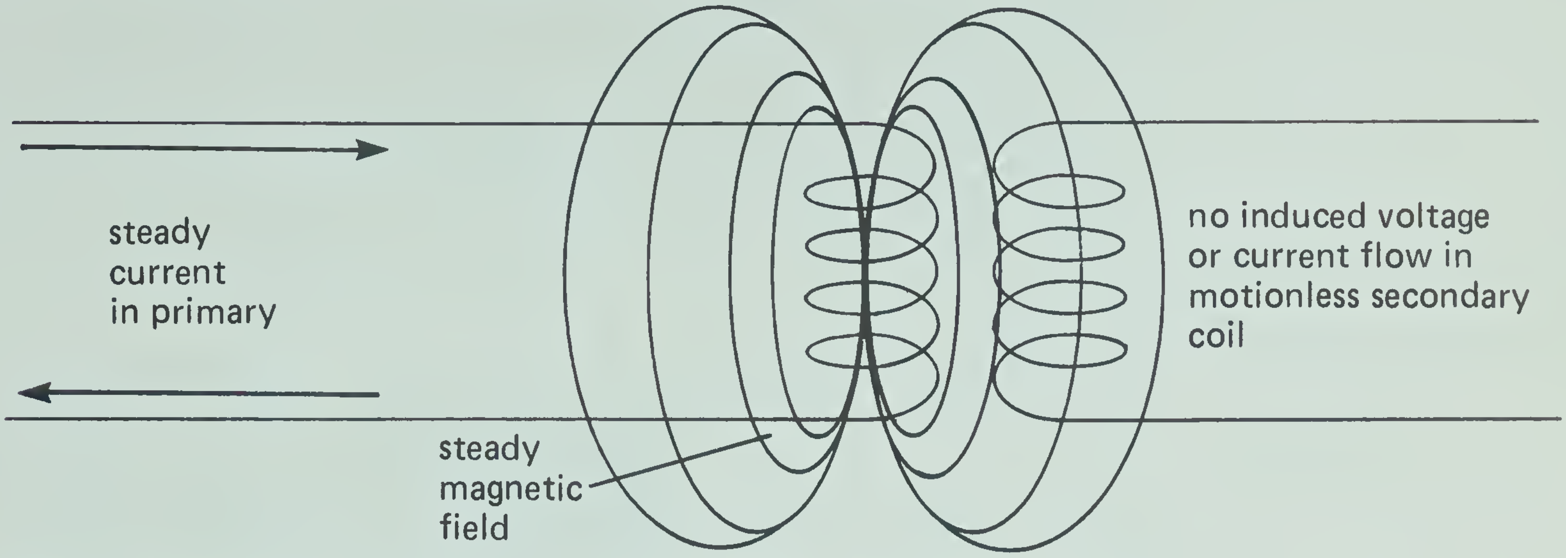
4. Frictional force depends upon the nature of the substances in contact and the condition of the touching surfaces.

5. All other things being equal, static friction is more effective than kinetic friction in overcoming inertia.

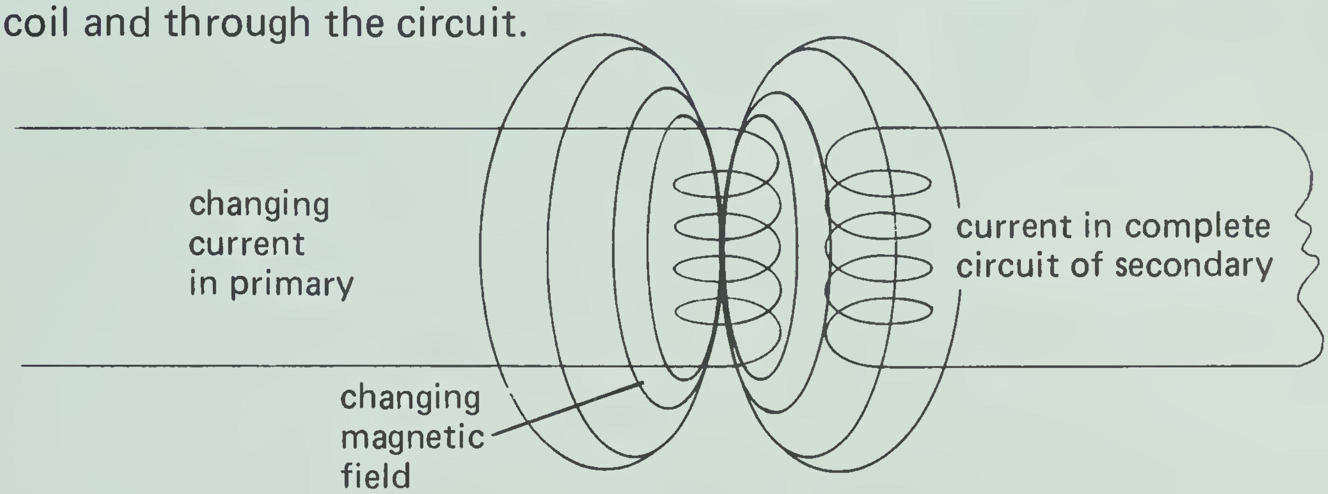
Ignition System

The theory of operation of an induction coil on an automobile is beyond the scope of the student's materials. For the student, a coil will probably be a "black box" that takes electricity at 12 volts potential and raises it to 15,000 to 30,000 volts. To understand how the coil does this, a person must have some knowledge of electric fields, which is suitable material for a course on electricity and magnetism. But sufficient information can be given here to provide you with some background in the subject.

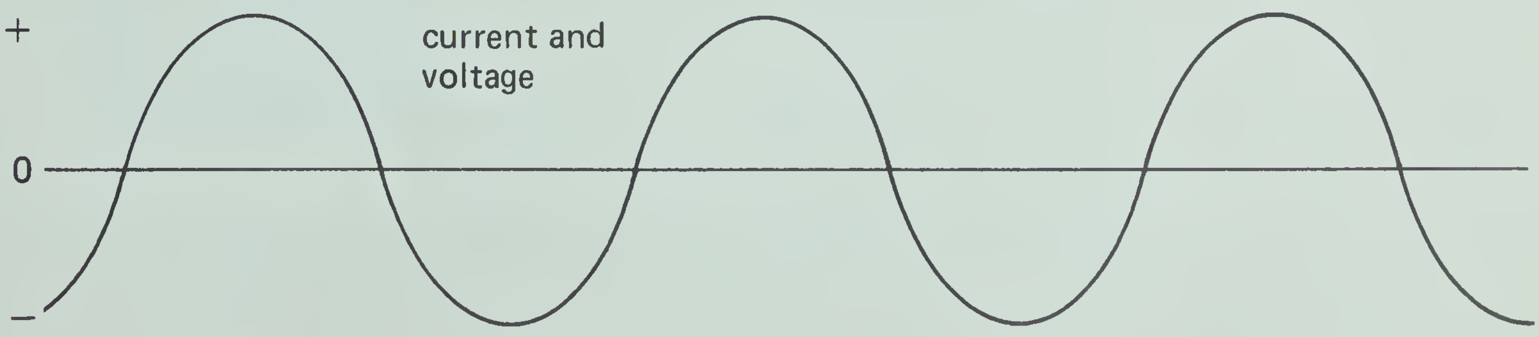
When current flows through a coil of wire, a magnetic field is set up. If the current is steady (neither increasing nor decreasing), the magnetic field is also steady. A steady magnetic field has no effect on another coil of wire that is motionless in the field.



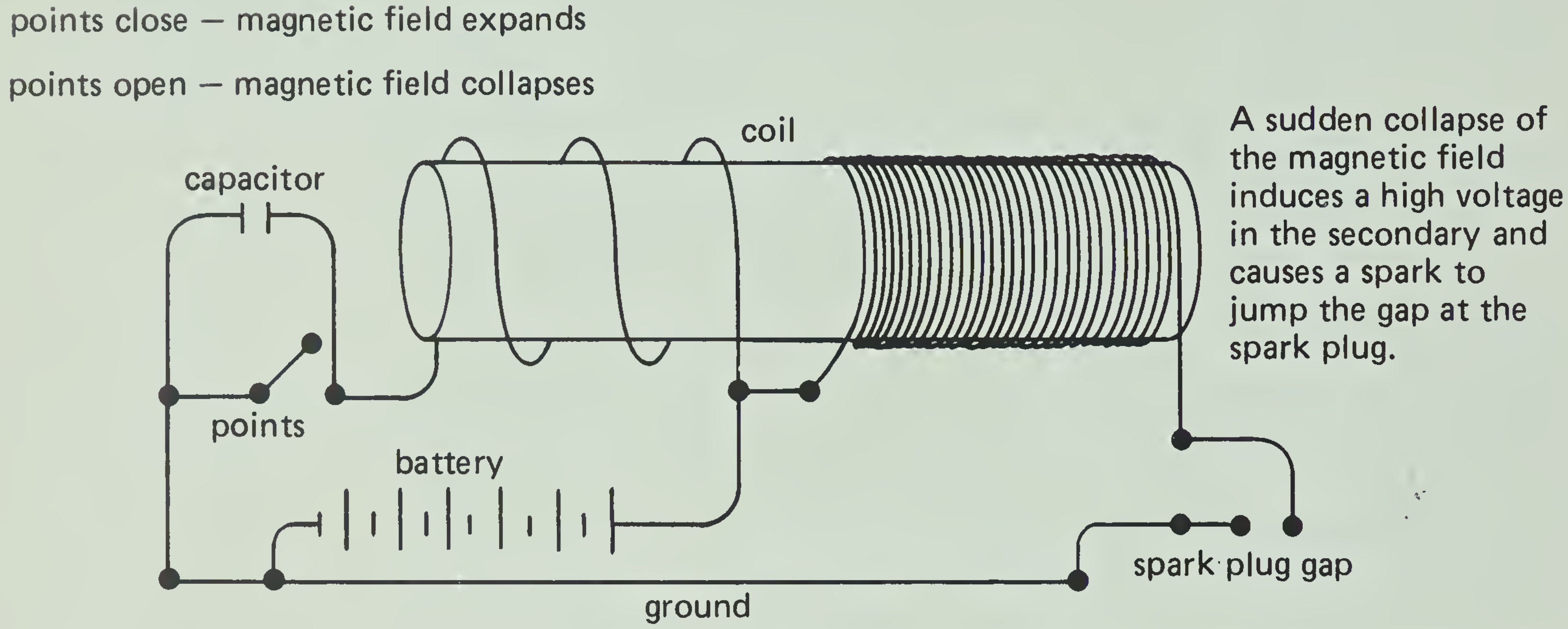
If the current in the wire coil changes (either increases or decreases), the magnetic field around the coil also changes. A changing magnetic field does affect another coil of wire in the field. It induces a potential across the coil. In other words, if the coil is connected in a circuit, it causes a current to flow through the coil and through the circuit.



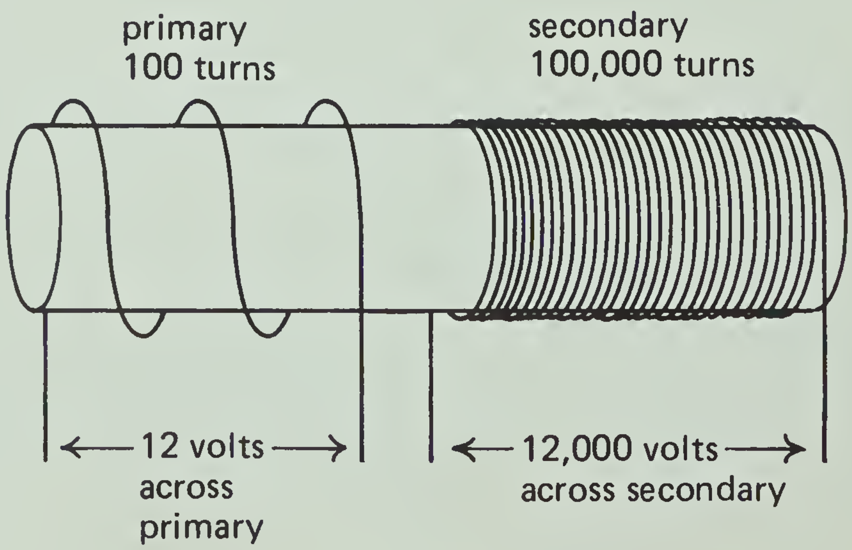
In transformers such as the one on the electric pole that furnishes power to a home, the magnetic field changes continually because the current in the primary coil changes continually. It uses alternating current, which changes from zero to maximum, to zero, to maximum in the opposite direction, and to zero sixty times every second. This causes the same current pattern to be set up in the other (secondary) coil in the transformer.



In the induction coil of an automobile, the changes in the current are accomplished by opening and closing the contact points in the distributor. When the points close, current surges through the primary coil, setting up an expanding magnetic field. When the points open, the electricity stops flowing and the magnetic field collapses. This expanding and collapsing magnetic field from the primary causes current to flow in the secondary, which is connected to the spark plugs.

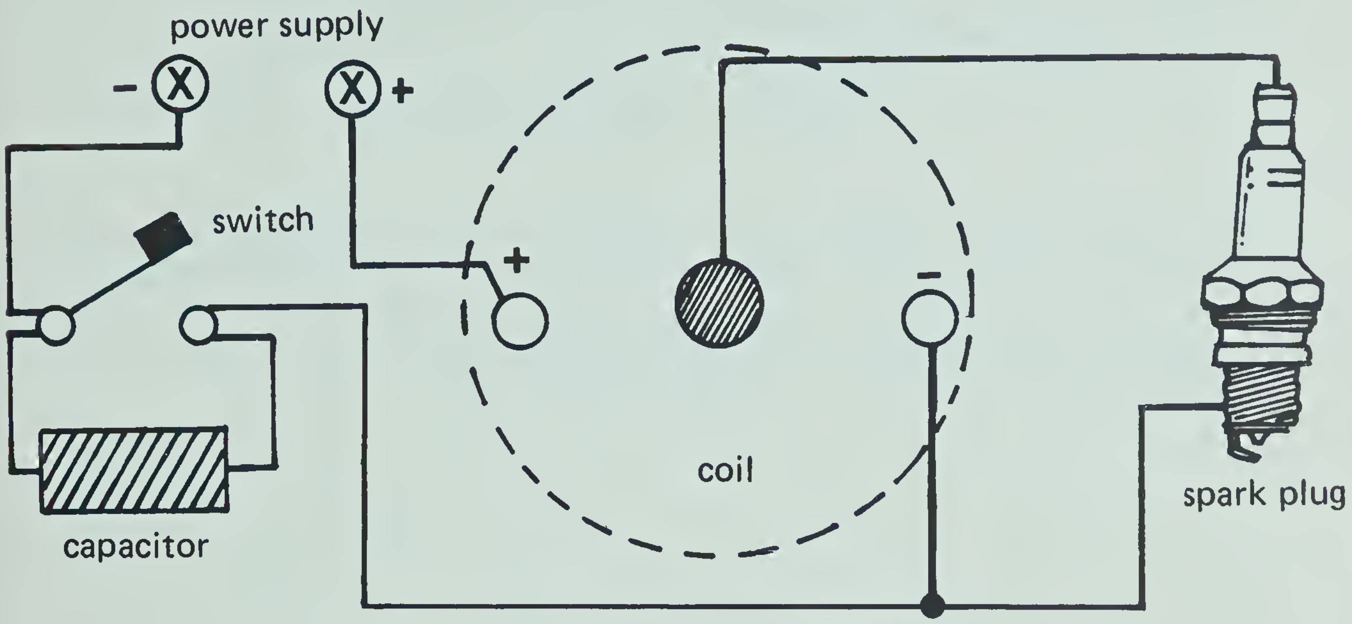


The ratio of the voltages across primary and secondary of transformers and induction coils is the same as the ratio of the number of turns of wire in the coils. For instance, if there are 10,000 turns on the primary coil and 1000 turns on the secondary coil, the ratio is 10 to 1. If a charge of 2300 volts is put across the primary, then 230 volts will be induced across the secondary. If there are fewer turns in the primary coil, then the voltage will be greater across the secondary. This is the case with the induction coil on a car. There are so many more turns in the secondary of the spark coil than in the primary, that the 12 volts from the battery can be boosted to thousands of volts.



The primary of the car coil has so few turns that current is very high when the coil is connected to a 12-volt battery. In practice, a resistor is used in the circuit to limit this current so that the coil doesn't burn out. In the investigation in Activity 4, no resistor is used. Consequently, the coil should not be left connected to the battery or power supply for long periods of time.

A diagram of the connections of power supply, switch, capacitor, coil, and spark plug is shown for your use in checking the circuit that students set up.



Demonstration Engines

Many high schools have auto mechanics courses. You may be able to arrange to have a demonstration or cutaway engine in your classroom for a short time. It would let students see firsthand the component parts and the four strokes of a gasoline engine. It would be especially helpful for students to be able to see the interrelationship between one part and another.

Small engines of the type used on lawn mowers and scooters are readily available from appliance repair shops for the asking. These worn-out engines will also help students who have had little experience with mechanical things.

Safety Contracts

ISIS strongly recommends that all students sign a safety contract early in the school year before beginning any minicourse. A sample safety contract can be found in *Managing ISIS*.

To help enforce the provisions of the safety contract, ISIS has placed various cautionary notes in the student's book. You will note that these cautions emphasize eye safety in particular.

Eye Safety

ISIS recommends that students wear safety goggles whenever they are working in a laboratory situation. Although a particular student may not be working with hazardous materials, other students nearby may be.

Working with Chemicals

Early in the school year, spend some time instructing your students on general laboratory safety and on appropriate precautions for working safely with chemicals. There are several general safety suggestions in *Managing ISIS*.

EVALUATION SUGGESTIONS

In addition to the *Minicourse Test*, answers to which are provided with the test, you may want to use the following essay questions.

Essay Questions

Three essay questions are included here with model answers for your convenience. All three relate to core material.

1. Describe a common problem associated with tires. Give its probable cause, a course of action for repair, and a way the problem might have been prevented. [The same question could be asked, substituting one of the following for *tires*: battery, spark plugs, radiator, carburetor, or lubrication.]

Answer: The tires are wearing bald in the middle of the tread. This is probably caused by overinflation. The tires will have to be replaced. This could have been prevented by checking tire pressures each week to ensure proper inflation.

2. Tell how the battery, distributor, spark plugs, and carburetor work together so your car starts and runs smoothly.

Answer: The battery supplies a voltage to the starter and the coil. The coil increases the voltage enough to cause the spark plug to fire. The distributor properly times and apportions the sparks to each cylinder. The carburetor mixes the right amount of fuel and air for proper burning after sparking.

3. You are preparing to go on a two-week trip during which you plan to travel 3000 km. What should you do to prepare your car? What should you check while traveling?

Answer: To prepare for the trip, do all of the following. Check the battery fluid level and charge. Check the radiator level and concentration. Check the tightness of the belts. Check the oil level. Replace the oil and filter if they will be due for changing before you return. Check tire pressure. Look for uneven wear, cracks, and nails. Check the timing, spark plugs, and pollution emission controls. Check the brake and transmission fluid levels (if applicable). While you are traveling, you should continue to check the battery fluid level, the radiator level, the belts, the oil level, and the tire pressure and condition daily.

REFERENCES

The Editors of Time-Life Books. *The Time-Life Book of the Family Car.* New York: Time-Life Books, Inc., 1973.
This is probably the best single reference for this minicourse for the teacher and students. It describes all major working systems in the car and illustrates their operation.

Stockel, Martin W. *Auto Mechanics Fundamentals.* rev. ed. Homewood, Illinois: The Goodheart-Wilcox Company, Inc., 1975.
This clear and profusely diagrammed textbook is not too difficult for most students.

Numerous magazines are devoted solely to cars. Many give annual reports on the new models. *Motor Trend, Car and Driver,* and *Road and Track* are general interest auto monthlies. *Consumer Reports* also tests and rates a great many cars each year.

Several car-repair manuals have become increasingly popular. The following are three that are useful.

Beau, Richard. *Basic Automotive Troubleshooting.* Los Angeles: Peterson Publishing Co., 1974.

Weiers, Ronald M. *More Miles-Per-Gallon Guide.* Radnor, Pennsylvania: Chilton Book Co., 1974.

Weissler, Paul, and Weissler, Arlene. *A Woman's Guide to Fixing the Car.* New York: Walker and Co., 1973.

The automotive industry and its service agents are also sources of information about cars. You might wish to contact local new-car dealers, service stations, parts stores, and tire dealers to see what pamphlets they can supply.

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acknowledgments

In addition to the major effort by the ISIS permanent staff, writing conference participants, and author-consultants (listed on the inside of the back cover), the following contributed to this minicourse.

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FOREWORD

Evidence has been mounting that something is missing from secondary science teaching. Increasingly, students are rejecting science courses and turning to subjects that they consider to be more practical or significant. Numerous high school science teachers have concluded that what they are now teaching is appropriate for only a limited number of their students.

As their concern has mounted, many science teachers have tried to find instructional materials that encompass more appropriate content and that allow them to work individually with students who have different needs and talents. For the most part, this search has been frustrating because, presently, such materials are difficult, if not impossible, to find.

The Individualized Science Instructional System (ISIS) Project was organized to produce an alternative for those teachers who are dissatisfied with current secondary science textbooks. Consequently, the content of the ISIS materials is unconventional, as is the individualized teaching method that is built into them. In contrast with many current science texts that aim to "cover science," ISIS has tried to be selective and limit the coverage to the topics that we judge will be most useful to today's students.

Obviously, the needs and problems of individual schools and students vary widely. To accommodate the differences, ISIS decided against producing tightly structured, presequenced textbooks. Instead, we are generating short, self-contained modules that cover a wide range of topics. The modules can be clustered into many types of courses, and we hope that teachers and administrators will utilize this flexibility to tailor-make curricula that are responsive to local needs and conditions.

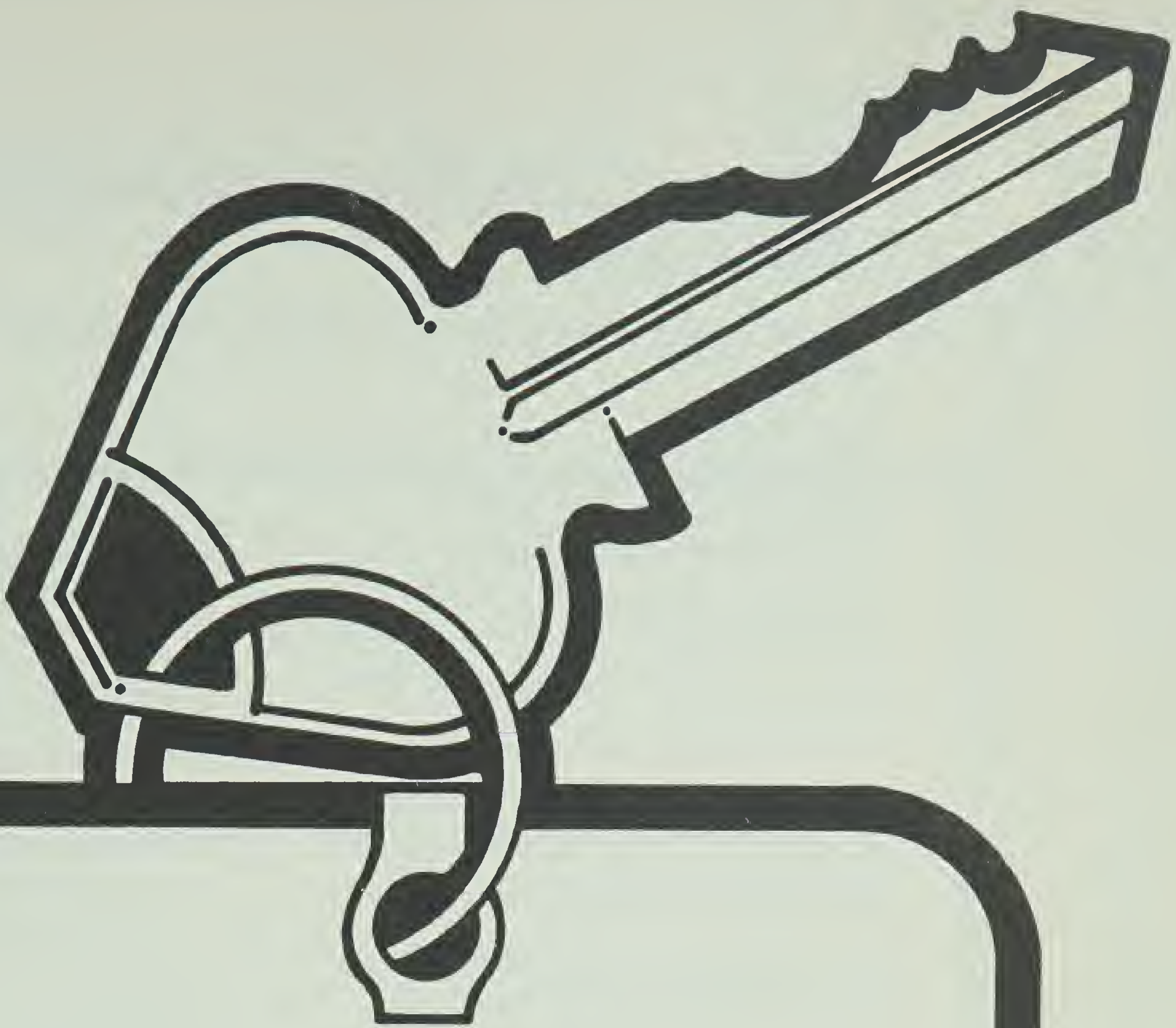
ISIS is a cooperative effort involving many individuals and agencies. More than seventy-five scientists and educators have helped to generate the materials, and hundreds of teachers and thousands of students have been involved in the Project's nationwide testing program. All of the ISIS endeavors have been supported by generous grants from the National Science Foundation. We hope that ISIS users will conclude that these large investments of time, money, and effort have been worthwhile.

Ernest Burkman

Ernest Burkman, Director
Individualized Science
Instructional System

The Florida State University
Tallahassee, Florida

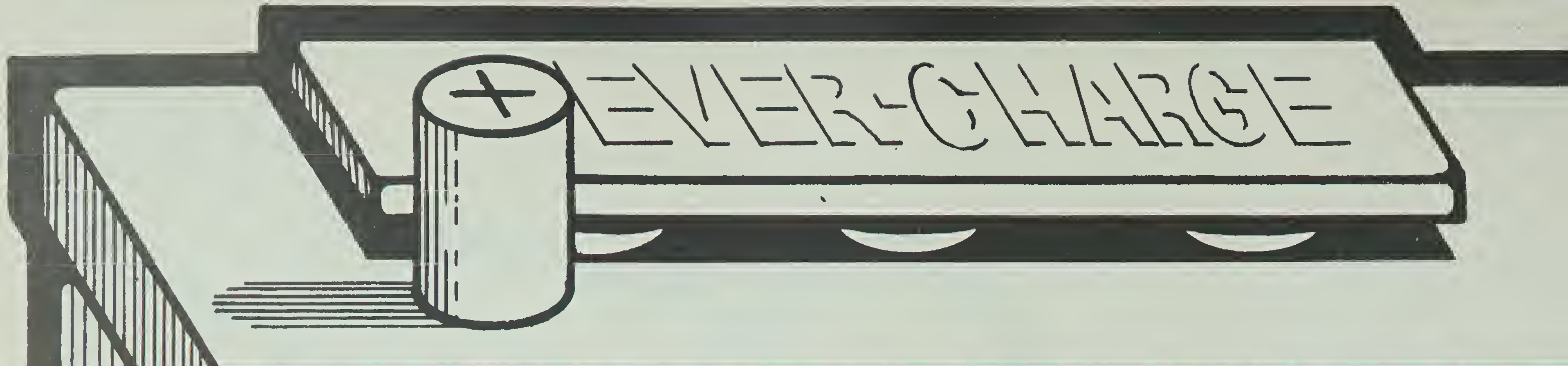
CONTENTS PAGE



WHAT'S IT ALL ABOUT?

A car is a collection of systems, and a car is a collection of parts.

When the systems and parts work as they should, that's fine. When they don't, there's trouble. And you need to know what's wrong. That's what this minicourse is all about.



CORE

ACTIVITY 1: PLANNING

If you plan to do Activity 2, do it right after you do this activity. The other activities may be done in any order.

Activity 2 — Page 5

Objective 2-1: Tell what is necessary for electricity to be used in a car.

Sample Question: A complete circuit
A. always contains at least four wires.
B. must contain a light bulb.
C. is a continuous pathway from and to a source of electricity.
D. has an open switch.

Activity 3 — Page 7

Objective 3-1: Tell what a battery is and what it does in a car, and describe the types of batteries.

Sample Question: A charged battery is necessary for
A. starting the car.
B. running the car after it has started.
C. operating the lights while the engine is running.
D. operating accessories, such as the radio, while the engine is running.

Objective 3-2: Describe how to care for and charge a battery, and tell what clues show that a battery is about to fail.

Sample Question: Which statement is true?
A. It's best to charge a battery before you refill it.
B. There's less chance of damaging the plates if you charge a battery by using a small current for a long time.

Activity 4 — Page 15

Objective 4-1: Tell what spark plugs do, and describe some common defects that cause spark plug failure.

Sample Question: What is the main job of the spark plugs in a car engine?
A. To ignite the air—fuel mixture
B. To insure that all sparks jump at the same time in all cylinders
C. To insure that the spark jumps at the proper time in each cylinder
D. To plug up the spark in the coil

Objective 4-2: Tell how the coil, points, and capacitor function in an ignition system, how to test for spark production, and how the common types of ignition systems differ.

Sample Question: In an ignition system using points and a coil, are the points in the low-voltage primary circuit or in the high-voltage secondary circuit?

Objective 4-3: **Describe what a distributor does, and explain why the setting of the timing is important.**

Sample Question: What is the main job of the distributor in a car engine?

A. To ignite the fuel
B. To insure that all spark plugs fire at the same time in all cylinders
C. To insure that the spark plug fires at the proper time in each cylinder
D. To keep the heater and air conditioning system working properly

Activity 5 — Page 23

Objective 5-1: **Tell how liquid cooling systems in cars work, what the most common causes of overheating are, and why antifreeze is used in all climates.**

Sample Question: What is one reason for using antifreeze in hot weather?

A. It lowers the freezing point below 0°C.
B. It raises the boiling point above 100°C.
C. It takes up less heat from the engine than water alone, so it never gets hot.
D. When the system overheats and breaks a hose, the antifreeze seals up the leaks.

Objective 5-2: **Explain why liquid cooling systems are pressurized, and tell how an overflow reservoir can be used with a pressurized system.**

Sample Question: Why are liquid cooling systems usually pressurized?

A. The coolant won't boil easily and evaporate.
B. The liquid can't splash out when the car is moving.
C. The overflow reservoir will be more efficient.
D. The overflow tube won't siphon the liquid out.

Objective 5-3: **Tell how a thermostat in a cooling system uses feedback control.**

Sample Question: When you start a cold engine, the coolant in the radiator is below the engine's best operating temperature. What does the thermostat in the cooling system usually do?

A. It stops the flow of coolant from the engine block.
B. It increases the flow of coolant from the engine block.
C. It turns on the car's heater.
D. It increases the speed of the fan.

Answers: **2-1.** C; **3-1.** A; **3-2.** B; **4-1.** A; **4-2.** the primary circuit; **4-3.** C; **5-1.** B; **5-2.** A; **5-3.** A

Activity 6 — Page 30

Objective 6-1: **Describe the functions of the parts of a fuel system, how a carburetor works, and the causes of some common troubles with an ordinary carburetion system.**

Sample Question: When your car failed to start and there was a strong odor of gasoline, you may have been told, "It's flooded." What does that usually mean?

A. Water has gotten into the air intake of the carburetor.

B. Water has been splashed on the engine or has condensed there from very humid air.

C. The choke has stuck open, failing to close when the engine cooled down.

D. The carburetor is mixing too much gasoline with the air.

Activity 7 — Page 36

Objective 7-1: **Tell what lubricants do and how to select lubricants properly.**

Sample Question: Suppose you're having the oil changed in your family car just before going on a long, summer car trip. What SAE number should you choose for the oil?

A. 30

B. 40

C. 5W20

D. 10W40

Activity 8 — Page 42

Objective 8-1: **Tell how tire pressure affects traction, tread wear, safety, fuel economy, and riding comfort.**

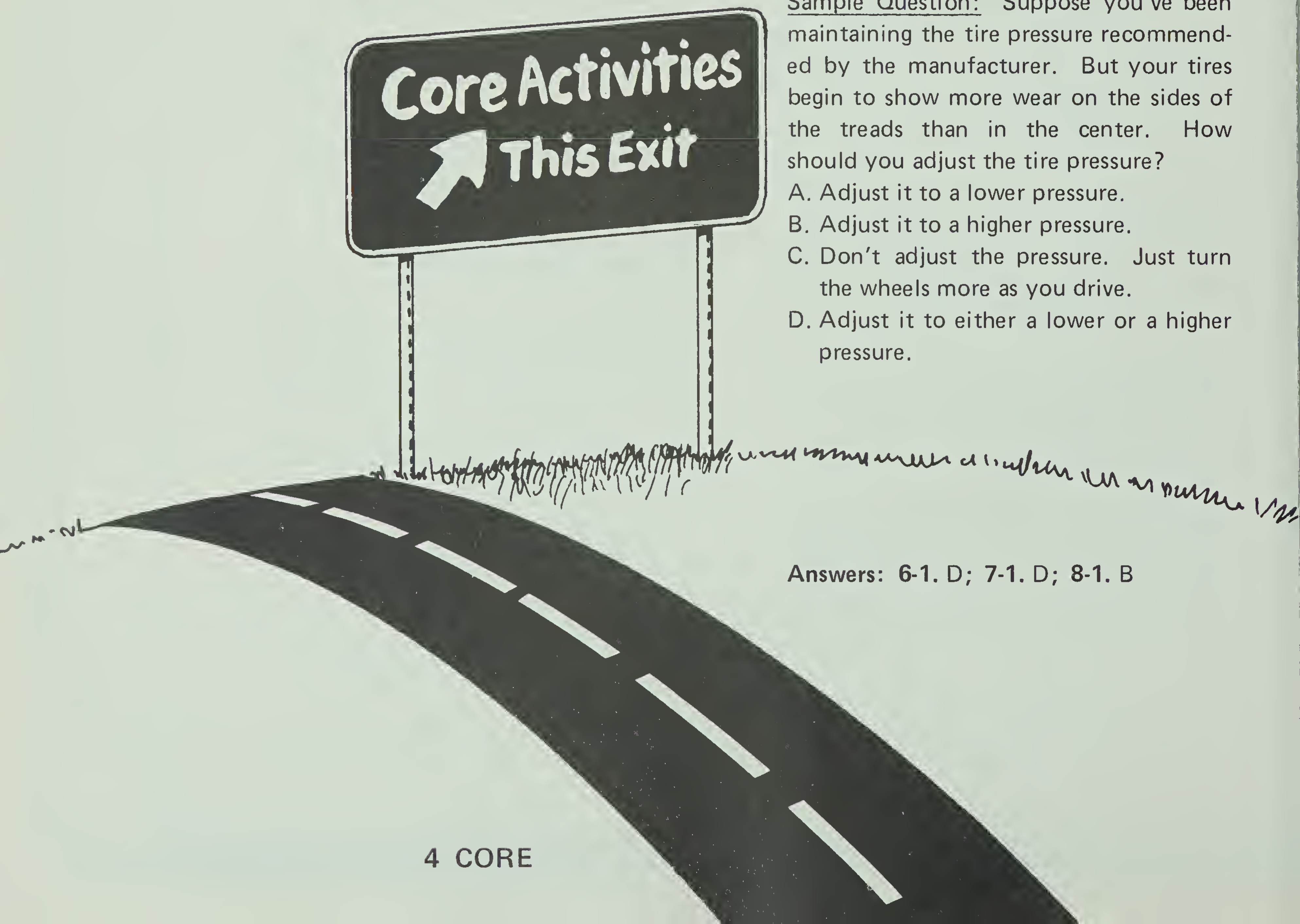
Sample Question: Suppose you've been maintaining the tire pressure recommended by the manufacturer. But your tires begin to show more wear on the sides of the treads than in the center. How should you adjust the tire pressure?

A. Adjust it to a lower pressure.

B. Adjust it to a higher pressure.

C. Don't adjust the pressure. Just turn the wheels more as you drive.

D. Adjust it to either a lower or a higher pressure.



Answers: **6-1.** D; **7-1.** D; **8-1.** B

ACTIVITY 2: CAR ELECTRICITY

ACTIVITY EMPHASIS: For electricity to be useful in an automobile, there must be a source, a complete pathway, and a method of controlling it.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

Electricity is used for many jobs in a car. It can light the lights, operate the radio or stereo, and run the heater or air-conditioner fan and windshield wipers. And it can heat the defroster wire and blow the horn. It is used to start the car and usually to ignite the gas—air mixture in the cylinders. In some cars, it works the windows, adjusts the seats, and runs the radio antenna up or down. It is even used in newer cars to turn the radiator cooling fan.

For electricity to do all these jobs, several things are necessary.

1. There must be a source of electricity. The source can be a battery or a generator.

2. There must be a continuous pathway, called a *circuit*. Then the electricity can travel from the source to the place it is used and back to the source.

3. There must be a means of turning it on and off.

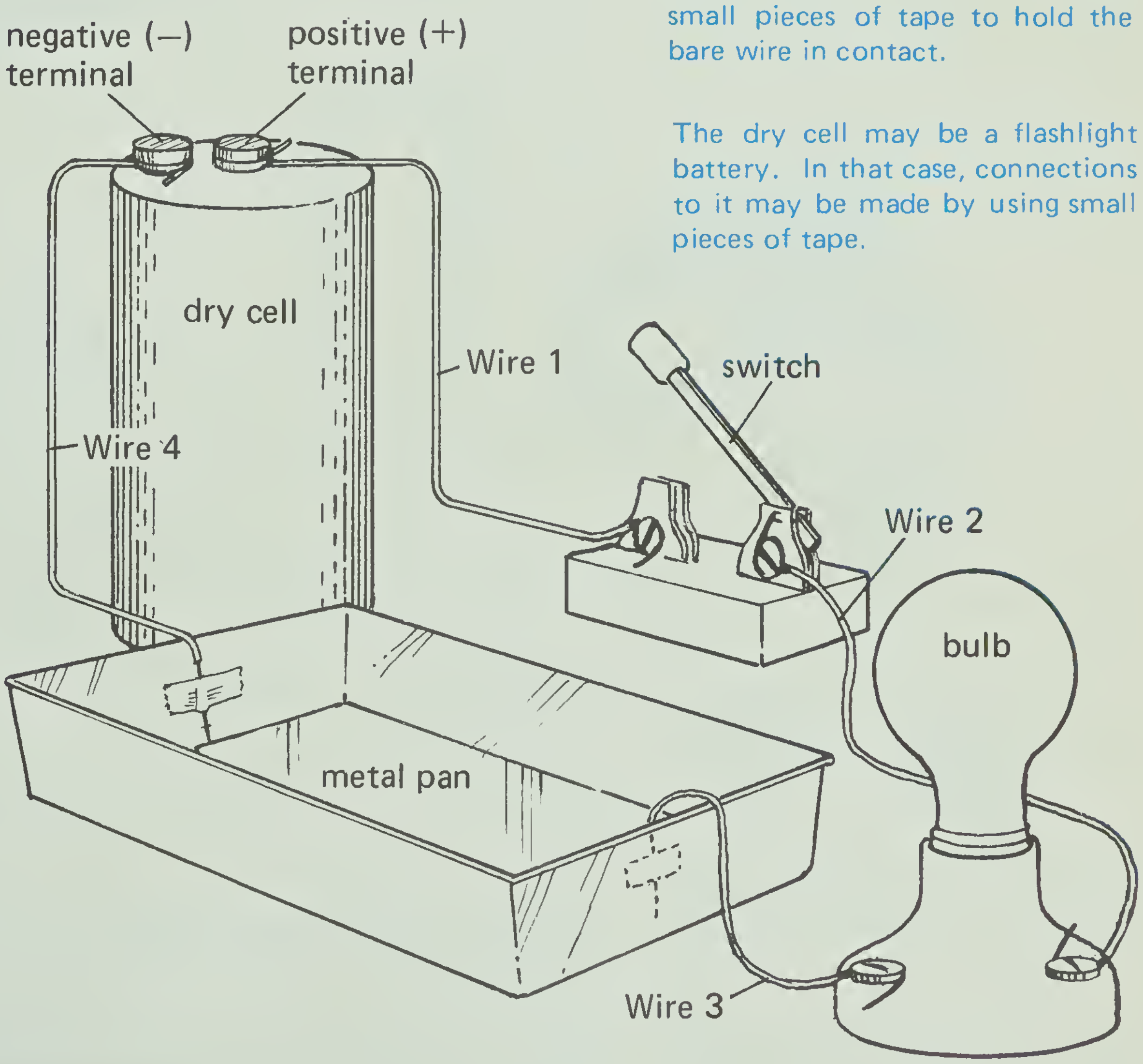
You can see how these things work. You will need the following materials.

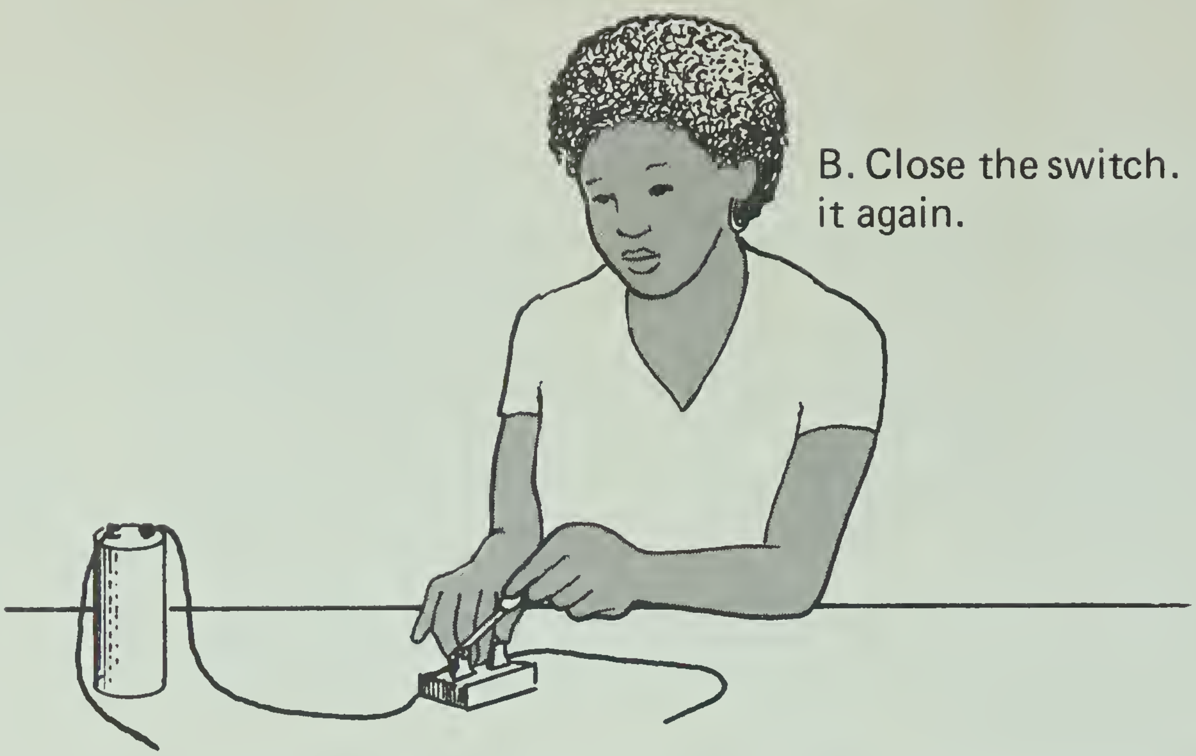
- 1.5 V dry cell
- 4 pieces of wire
- switch
- flashlight bulb and socket
- metal pan
- 4 cm of tape or 8 clips

Connections to the pan may be made with clips or by using small pieces of tape to hold the bare wire in contact.

The dry cell may be a flashlight battery. In that case, connections to it may be made by using small pieces of tape.

A. Connect the wires as shown, using tape or clips. Wire 1 goes from the positive (center) terminal of the dry cell to one side of the open switch. Wire 2 goes from the other side of the switch to one terminal of the light-bulb socket. Wire 3 goes from the other light-bulb terminal to one side of the metal pan. Wire 4 goes from the other side of the pan to the negative (side) terminal of the dry cell.





B. Close the switch. Then open it again.

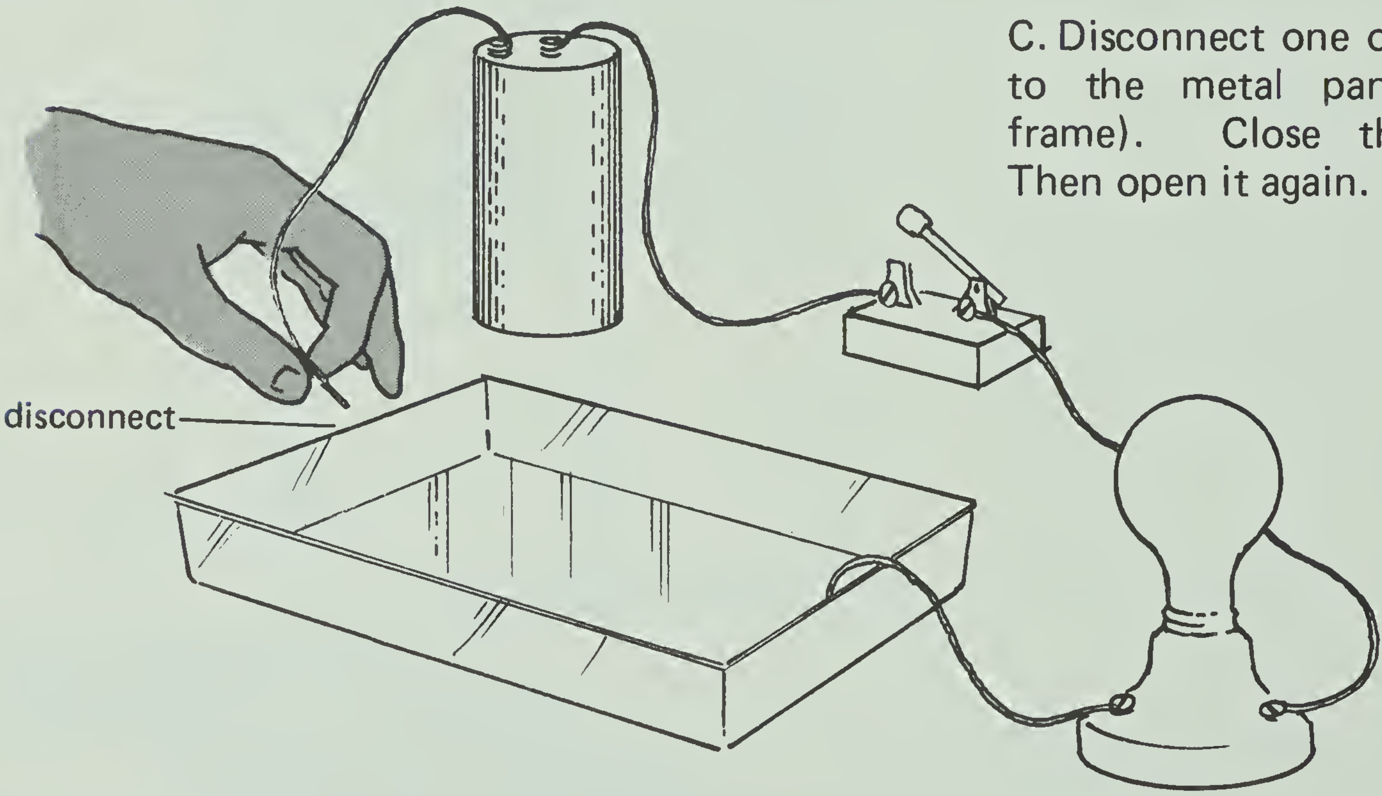
When you closed the switch, the bulb should have lit. If it didn't, there is probably something wrong with your circuit. You must have a complete, continuous pathway for electricity to flow. Of course, the dry cell and the light bulb must be working too.

A car often uses the metal frame and the engine as part of the circuit. In your circuit, you used a metal pan.

2-1. The frame

• 2-1. What did the metal pan most nearly represent in a car?

C. Disconnect one of the wires to the metal pan (the car frame). Close the switch. Then open it again.



2-2. No; when you disconnected the wire from the metal pan, there was no longer a complete circuit.

2-3. There must be a source, a complete pathway for it to travel, and a means of control.

• 2-2. Did the bulb light? Explain your answer in terms of a circuit.

☆ **2-3. What three things are necessary for electricity to do various jobs in a car?**

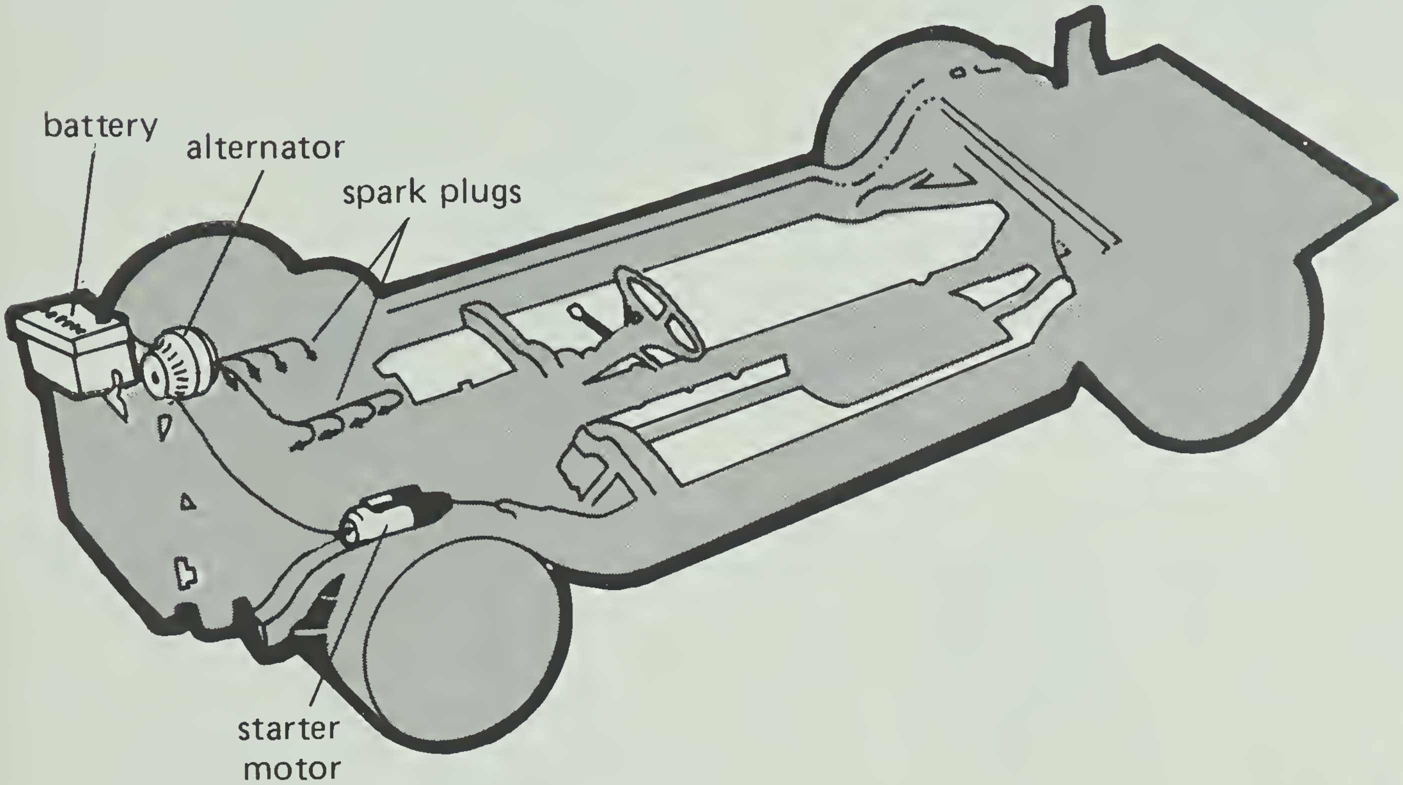
ACTIVITY 3: BATTERIES AND STARTING

When you get into a car to drive, the first thing to do is fasten your seat belt and adjust the seat and mirrors. Then you start the engine. And that's the time you need a good battery.

Most cars have a lead–acid storage battery. It supplies electricity to the starter motor and, at first, to the spark plugs that ignite the gasoline.

ACTIVITY EMPHASIS: The storage battery in a modern car furnishes the necessary electricity for starting, spark plugs, and electrical accessories. But for it to do so, the battery must be cared for and kept charged. Even then it is subject to failure.

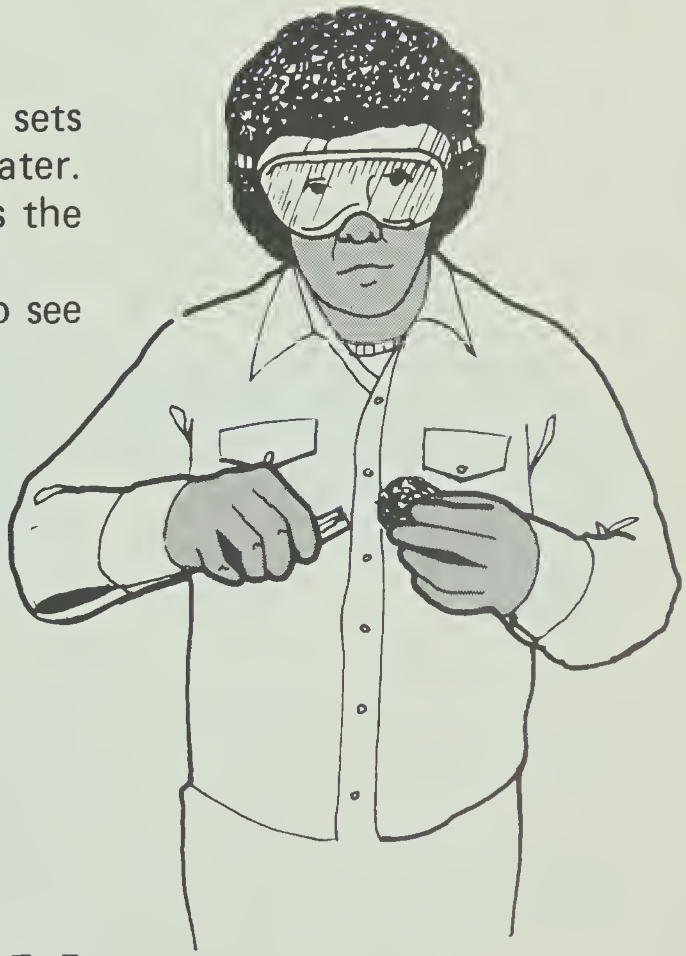
MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

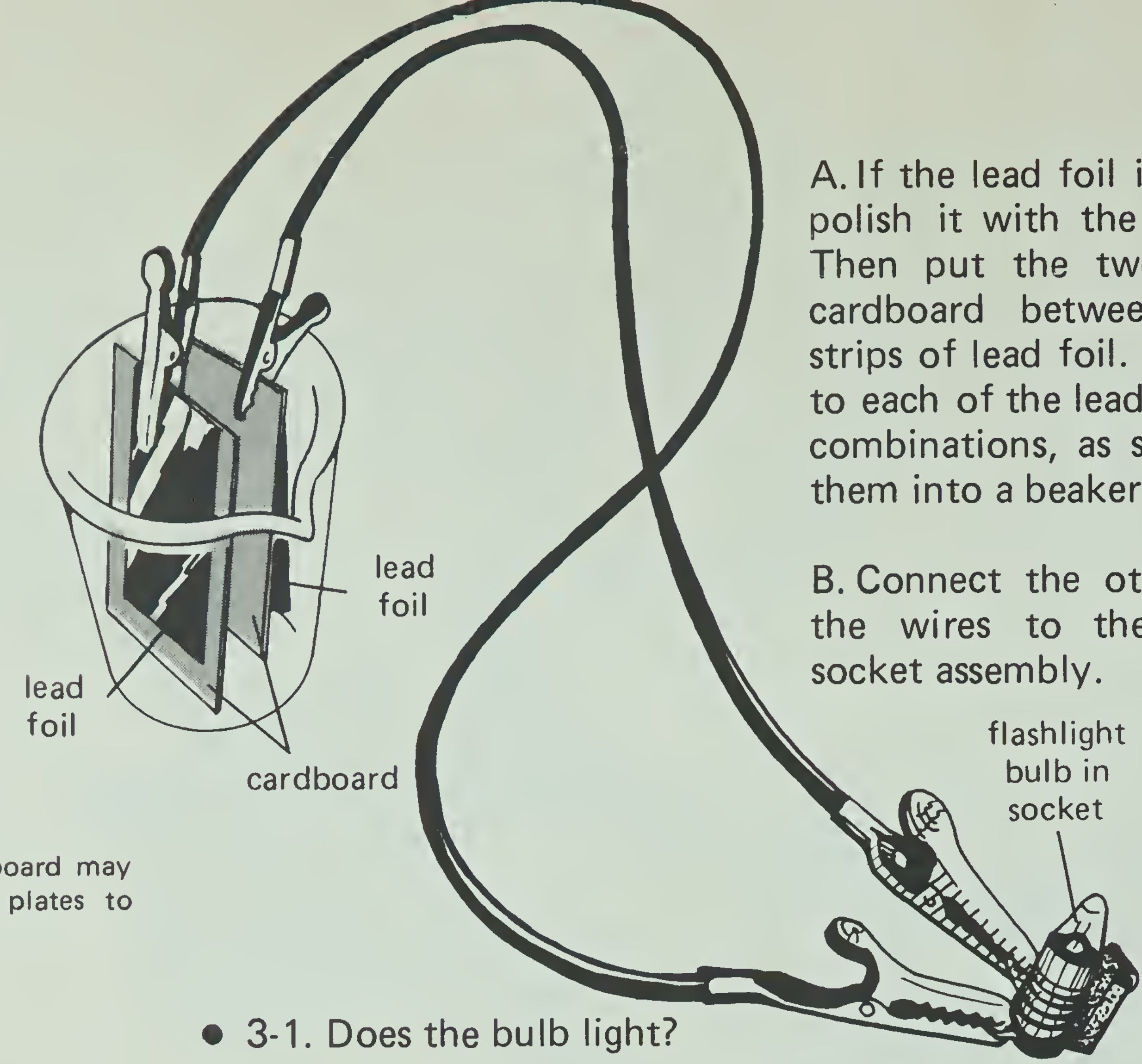


A car battery usually contains six cells. Each cell has two sets of plates in a solution of sulfuric acid – acid mixed with water. When the battery supplies electricity to something such as the starter motor, a chemical reaction takes place.

You can make a smaller version of one of these cells to see how it works. You will need the following materials.

- safety goggles
- 2 50-ml beakers
- 2 pieces of lead foil, about 3 cm X 6 cm
- 2 pieces of cardboard, about 3.5 cm X 7 cm
- sulfuric acid solution
- 2 wire leads with clips
- flashlight bulb and socket
- power supply or battery, 4 to 6 volts
- watch or clock with second hand
- steel wool





A. If the lead foil is not shiny, polish it with the steel wool. Then put the two pieces of cardboard between the two strips of lead foil. Clip a wire to each of the lead–cardboard combinations, as shown. Put them into a beaker.

B. Connect the other ends of the wires to the bulb and socket assembly.

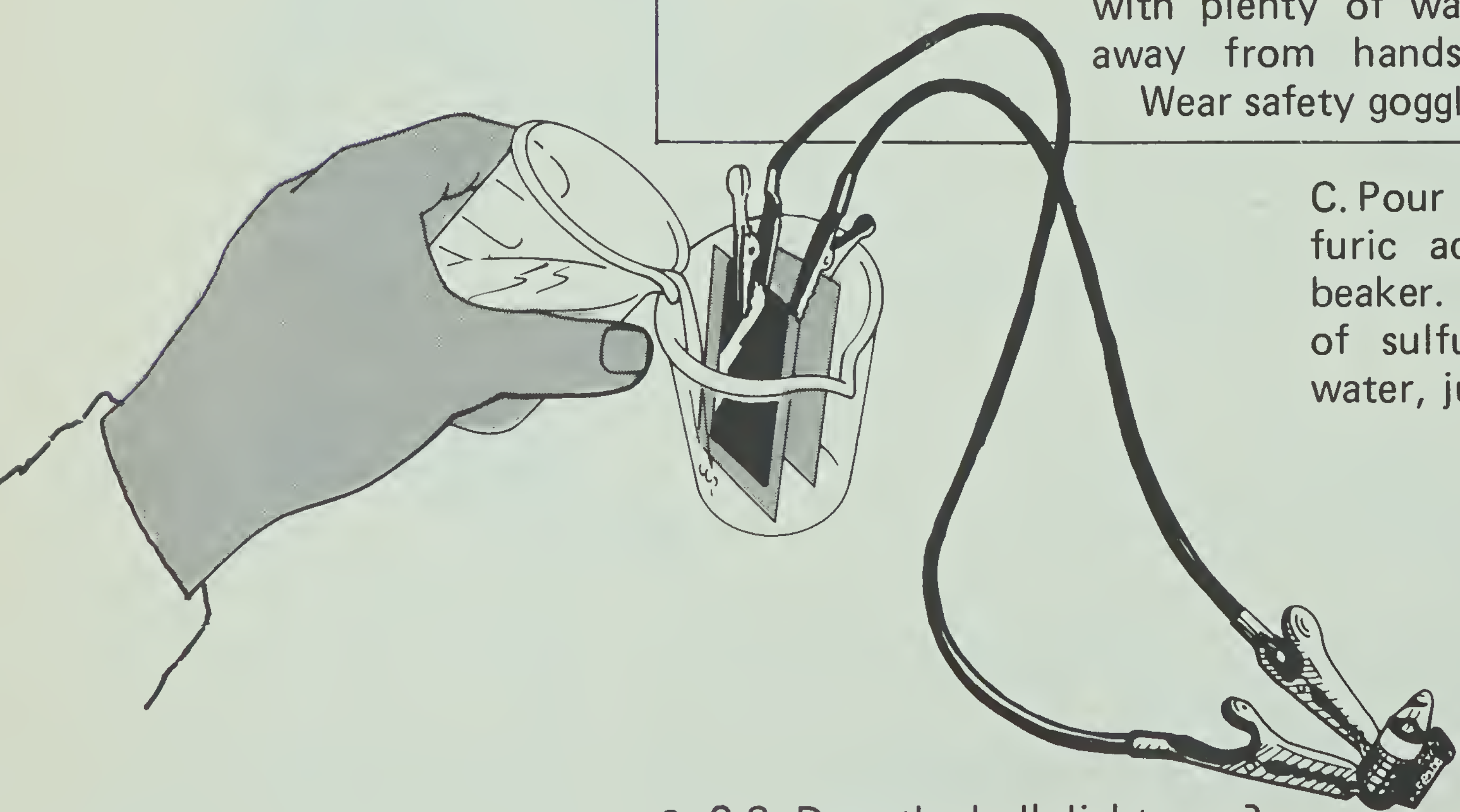
A third piece of cardboard may be used between the plates to give added separation.

3-1. No

• 3-1. Does the bulb light?

If the bulb didn't light, don't get discouraged. Go on. Apparently, it takes more than lead strips and cardboard to make electricity.

CAUTION	Sulfuric acid is a powerful and corrosive substance. Be careful using it. If any is spilled, rinse the area with plenty of water. Keep acid away from hands and clothing. Wear safety goggles.

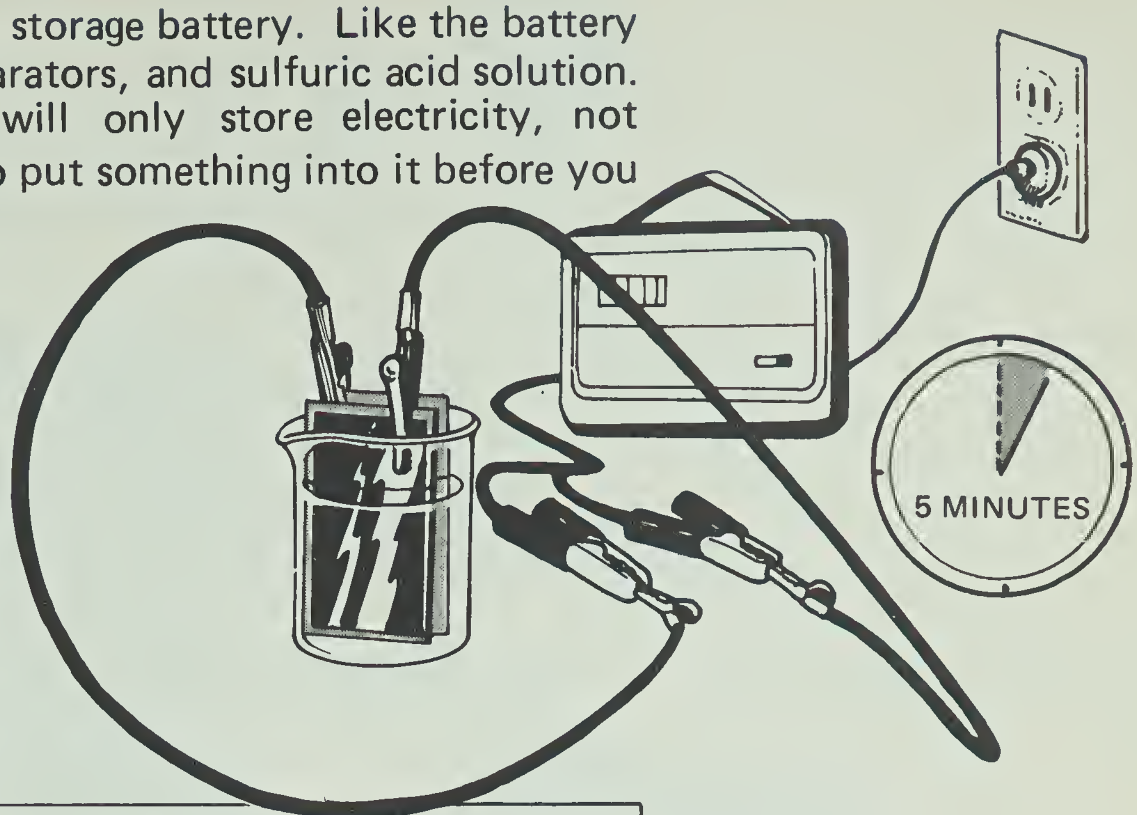


C. Pour about 40 ml of sulfuric acid solution into the beaker. This solution is made of sulfuric acid mixed with water, just as in a car battery.

3-2. No

• 3-2. Does the bulb light now?

You have made one cell of a storage battery. Like the battery in a car, it has lead plates, separators, and sulfuric acid solution. Also like a car battery, it will only store electricity, not generate it. And so you have to put something into it before you can get anything out.



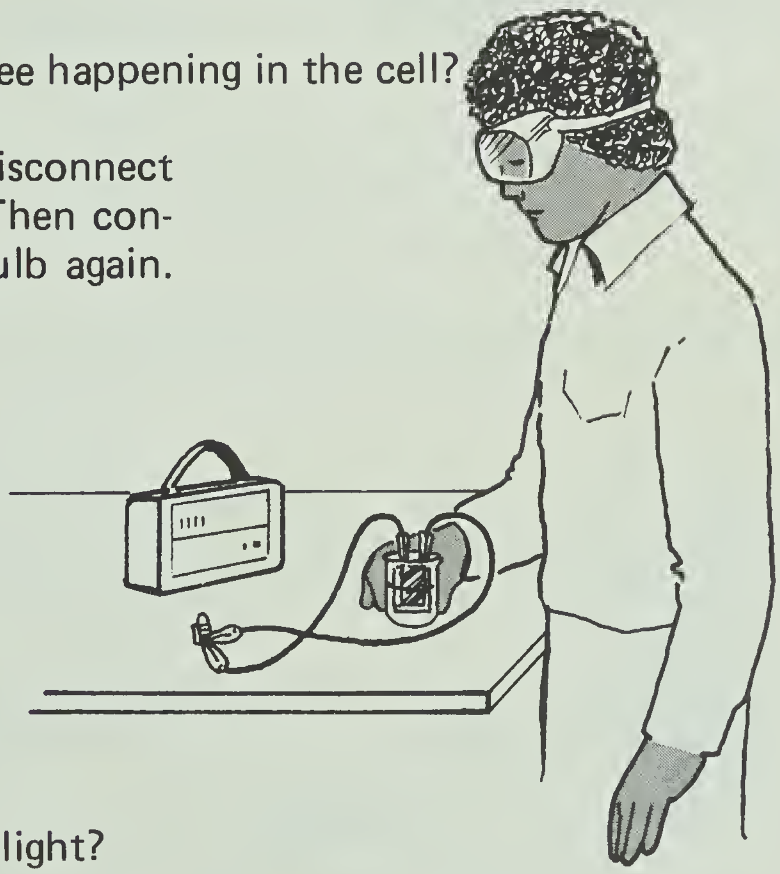
D. Disconnect the bulb. Connect the two wires to the power supply or battery. Notice the way the wires are connected. Be sure to connect them the same way each time you do it. Leave everything connected for 5 minutes while you watch the cell.

CAUTION	Don't use a power supply of more than 12 volts.

• 3-3. What do you see happening in the cell?

3-3. Bubbles are coming from the two lead plates. One of the plates is changing color.

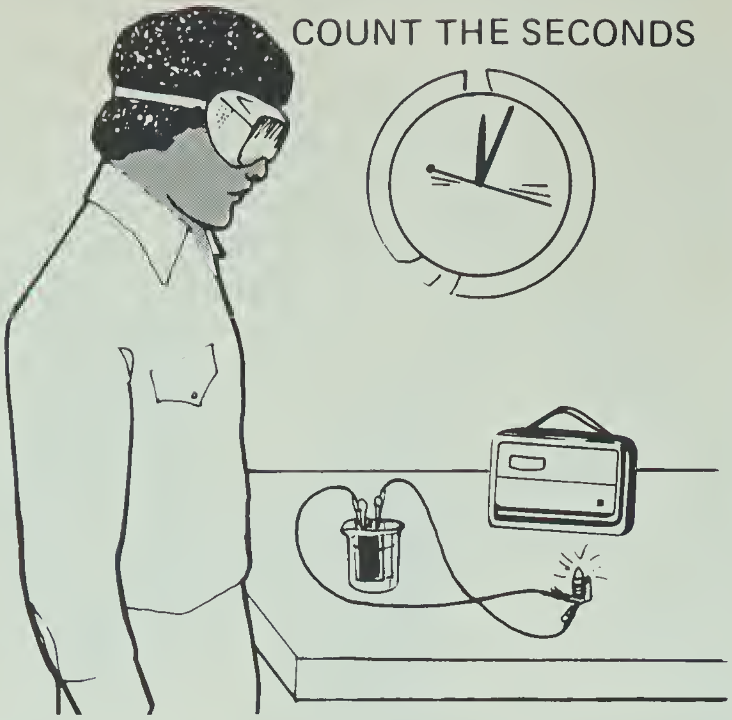
E. After 5 minutes, disconnect the power supply. Then connect the flashlight bulb again.



• 3-4. Does the bulb light?

3-4. Yes

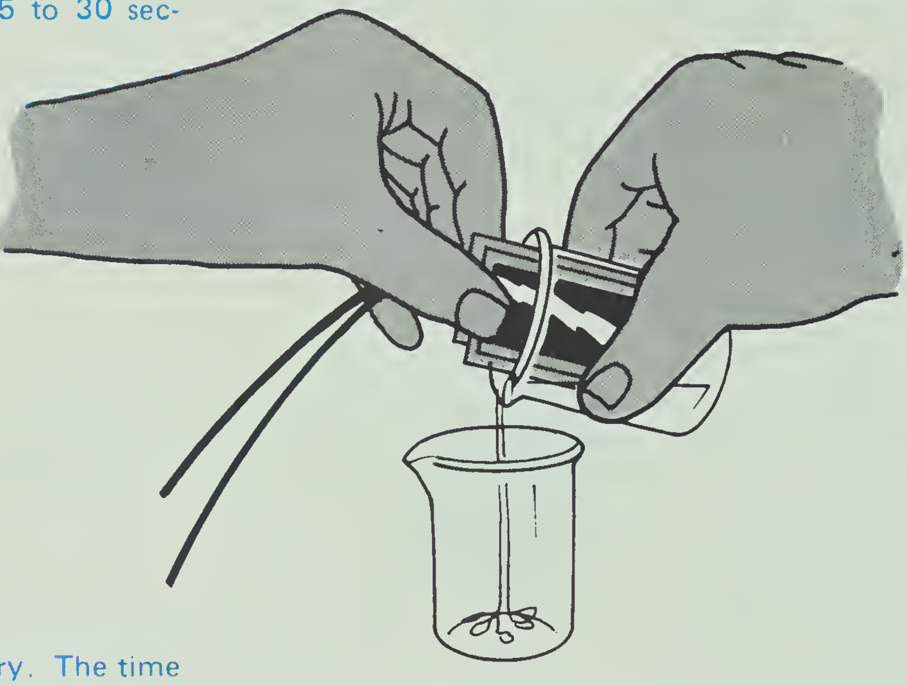
The bulb probably didn't stay lit very long. That's not surprising. Your lead strips are small compared to the many plates in a car battery. Besides, you charged your cell for only five minutes. The longer you charge your cell, the better it will operate.



F. Recharge your cell for another 5 minutes. Be sure it's connected in the same way as before. If you reverse the leads, you'll have trouble. Then disconnect the power supply, and connect the bulb again. Count the number of seconds that the bulb stays lit.

3-5. [Answers will vary but will probably be from 15 to 30 seconds.]

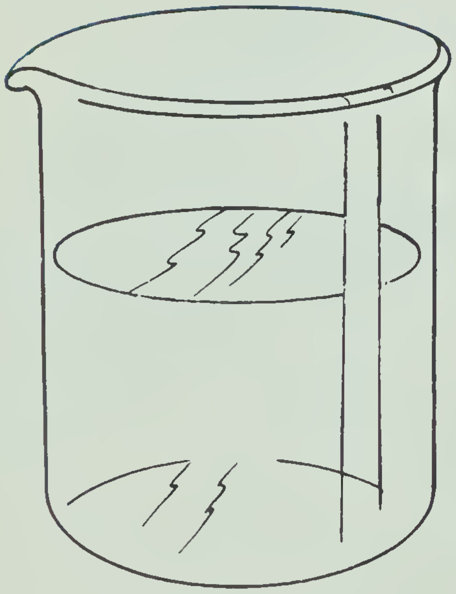
● 3-5. How long did the bulb stay lit?

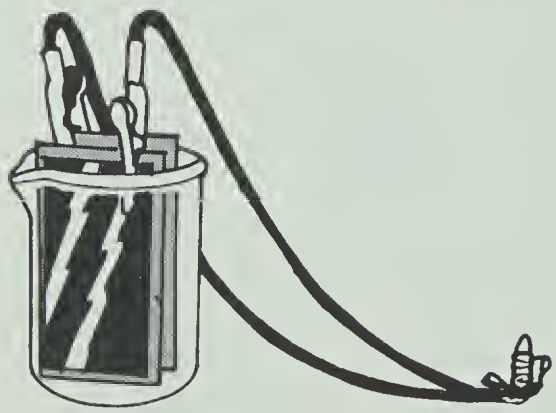


G. Recharge your cell for another 5 minutes. Disconnect the power supply. Carefully pour about half the sulfuric acid solution into the other beaker. Then reconnect the bulb. Measure the time in seconds that the bulb stays lit.

3-6. [Answers will vary. The time should be less than in Question 3-5.]

● 3-6. With only half the fluid left in the cell, how long does the bulb stay lit?





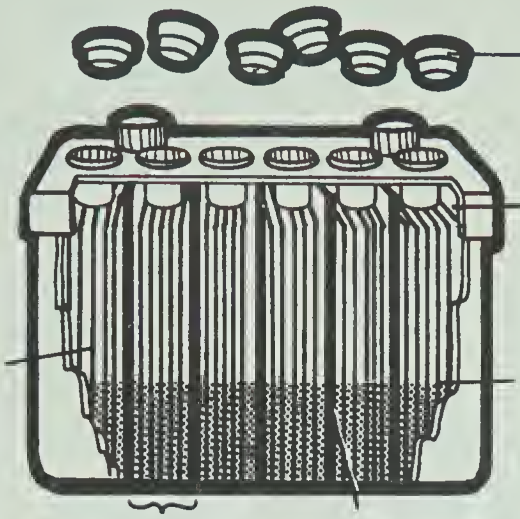
H. Carefully pour the rest of the sulfuric acid into the second beaker. Let the liquid remain undisturbed for a few minutes as you go on with this activity.

One of the things that careful car owners do often is check the fluid level in their car batteries. In fact, in warm weather, they may check it every time they get gasoline.

3-7. The fluid level in the cells

☆3-7. What important condition of a regular storage battery must be checked often?

A battery has several cells, and each cell has many plates in it. That provides a large area of contact between the plates and the battery fluid. Then the chemical reaction will occur fast, delivering the needed electricity. But if the fluid level is allowed to drop, the contact area is reduced. That means less reaction and less electricity.



☆3-8. **Explain what a car battery is, in terms of its structure and operation.**

3-8. A battery is a device that delivers stored electricity by means of a chemical reaction between lead and acid.

☆3-9. **What's the most important function of the battery in a car?**

3-9. To provide electricity for starting the car

Some newer storage batteries have no cell caps. You never have to add water to keep the correct fluid level. The battery has a much longer life than the older type of battery.

☆3-10. **What is a major difference between caring for older and newer types of car batteries?**

3-10. You never need to add water to some newer batteries, but you do with older ones.

To stay useful, of course, a battery must stay charged. Charging is normally done automatically by the car's alternator. The alternator, or alternating generator, operates whenever the car's engine is running.

But sometimes this normal charging isn't enough. Sometimes a car will be started often and driven only for short distances. Sometimes the accessories, such as radio, lights, and windshield wipers, get used a lot when the engine isn't running. And sometimes the car is allowed to sit unused for weeks at a time.

Under those conditions, the battery may run down. Then it needs a boost from an outside power source.

The chemical reactions for the charging and discharging of the storage battery might be of interest to some students.

$$2\,PbSO_4 + 6\,H_2O \underset{\text{discharging}}{\overset{\text{charging}}{\rightleftarrows}} Pb + PbO_2 + 4\,H_3O^+ + 2\,SO_4^{=}$$

• 3-11. Now, examine the beaker of sulfuric acid solution. What do you see in the bottom of the beaker?

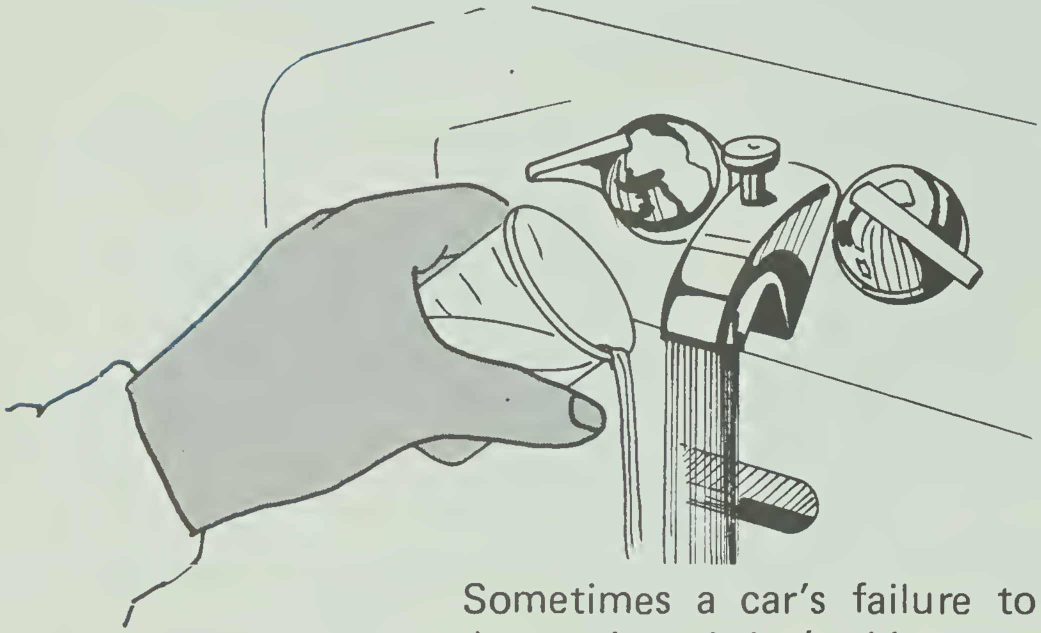
3-11. A white substance

The substance you see is a chemical formed when a lead–acid storage battery discharges. When the white chemical collects in the bottom of the cells, it can cause battery failure.

Another source of battery trouble is bad connections. Often, a whitish powder, caused by corrosion, will collect at the battery terminals. It must be cleaned off with a wire brush or washed off with a solution of baking soda. Otherwise, it may destroy the connection or short out the battery.

3-12. It must be cleaned off with a wire brush or baking soda solution.

☆ **3-12. What must be done if a whitish substance forms on the battery terminals?**



I. Dispose of the acid solution by pouring it into the sink under fast-running water. Rinse out the beakers and rinse off the electrical connections. Throw away the cardboard. Rinse off the lead strips. They can be reused.

Sometimes a car's failure to start is due to battery failure, and sometimes it isn't. You need to be able to recognize whether or not the trouble is with the battery. Look at Figure 3-1 below.

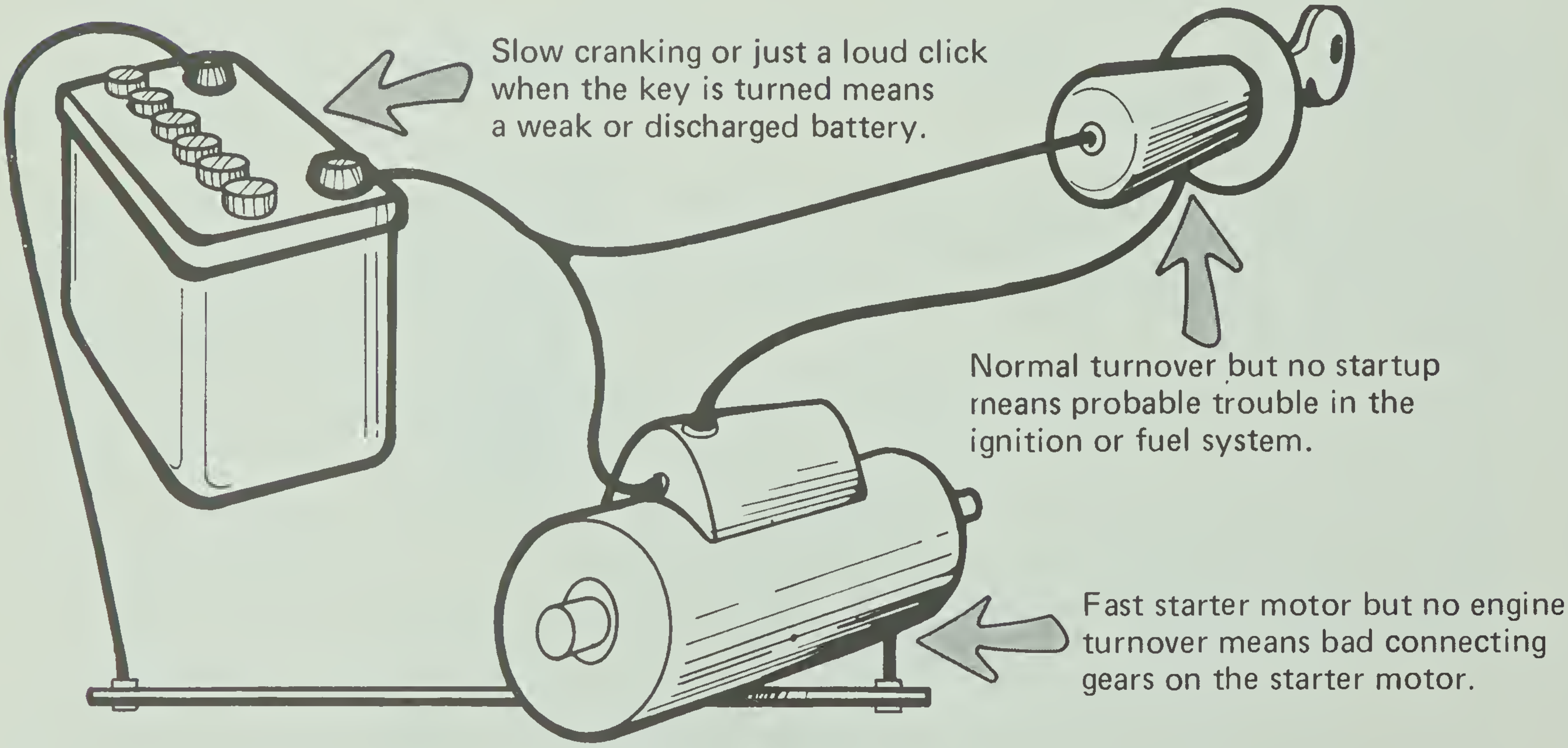
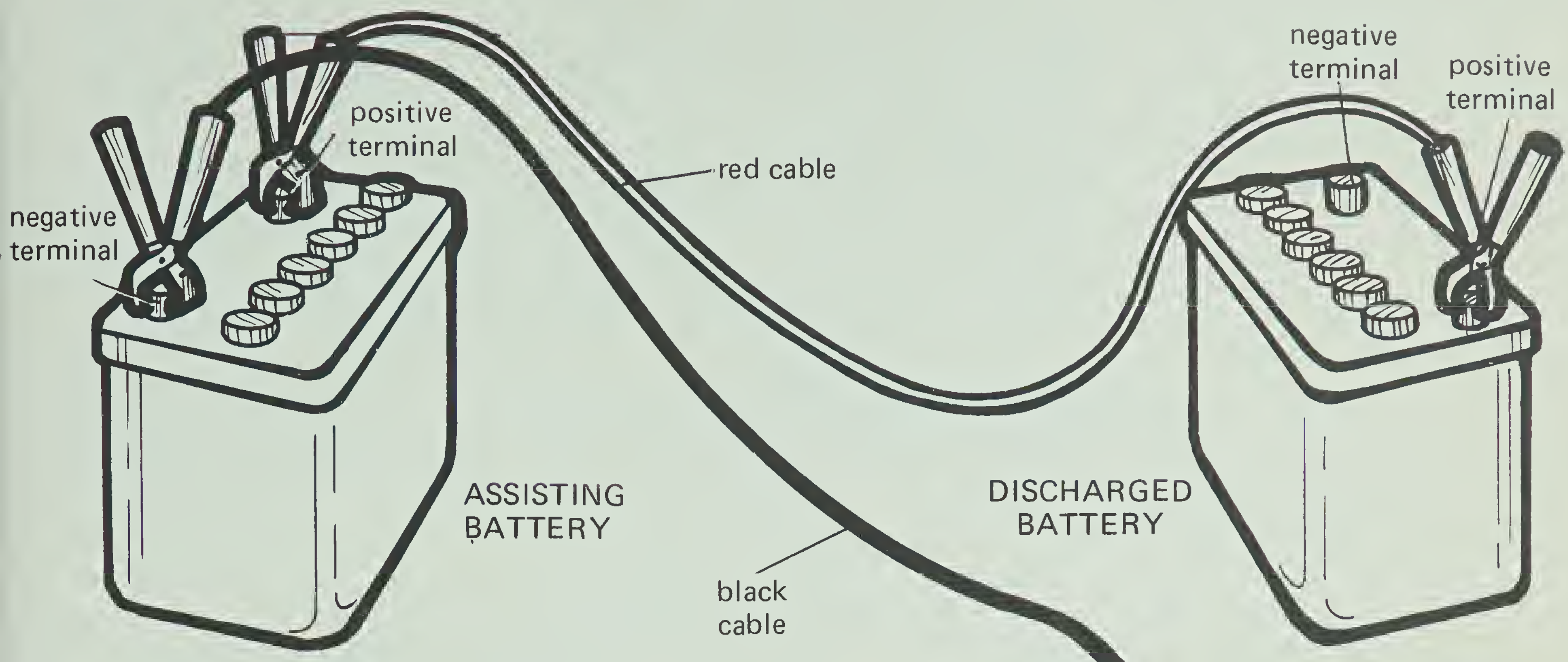


Figure 3-1

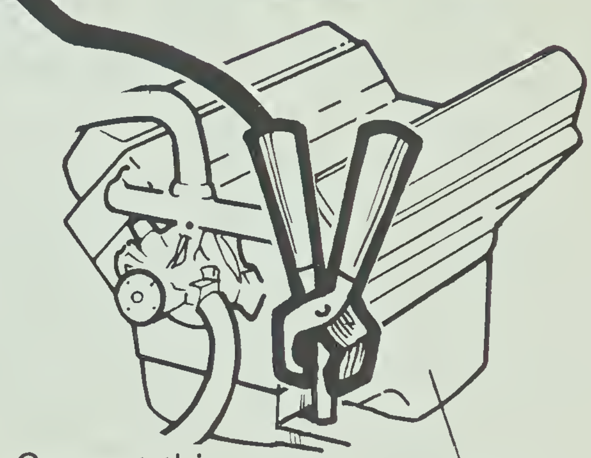
Suppose you have trouble starting your car. And suppose the trouble is in the battery. A common temporary solution is to jump-start the car, using cables connected to another car's battery. Figure 3-2 below shows the safe and correct method for doing this.



1. Turn off the ignitions of both cars. Be sure cars are NOT touching each other. Put out all flames. Remove watches and rings from hands. (Cables should not touch any stray metal.) Make sure all accessories are turned off in both cars.

2. Connect the clamps of the red cable to the positive terminals (plus poles) of the two batteries. Never connect a positive to a negative! That can ruin the batteries.

3. Connect one clamp of the black cable to the negative terminal (minus pole) of the assisting battery. Connect the other clamp of the black cable to the engine block of the car to be started. Always connect that ground cable last.



4. Start the engine of the assisting car. This allows its alternator to help supply the electricity instead of just draining the assisting battery.

5. Start your car's engine. Once it's going, cut the engine of the assisting car. Then remove the cable clamps in the reverse order from the way you connected them. Be careful not to touch the clamps to any metal or to each other.

Figure 3-2

3-13. To the positive terminal of your own car

☆3-13. **Suppose you are jump-starting your car. You have just attached a clamp of the red cable to the positive (+) terminal of the assisting car's battery. Where should you attach the other clamp of the red cable?**

Jump-starting is just a stopgap solution. It gets your car running, but it can't fix a bad battery. If your battery has just run down, it can probably be recharged and brought back into service. But if it's failing, it may need to be replaced.

Check the fluid level. If it's low, look for cracks and fluid leaks in the case. If there are none, fill the battery to the proper level and recharge it. If it still can't hold a charge, it's probably failing. You should have it checked by a mechanic.

Sometimes a weak battery can be recharged by the car's alternator. But if your battery needs an external charge, it's better to make it a slow charge — overnight, at least. A fast charge (say, half an hour) shortens battery life. Look at Figure 3-3 below.

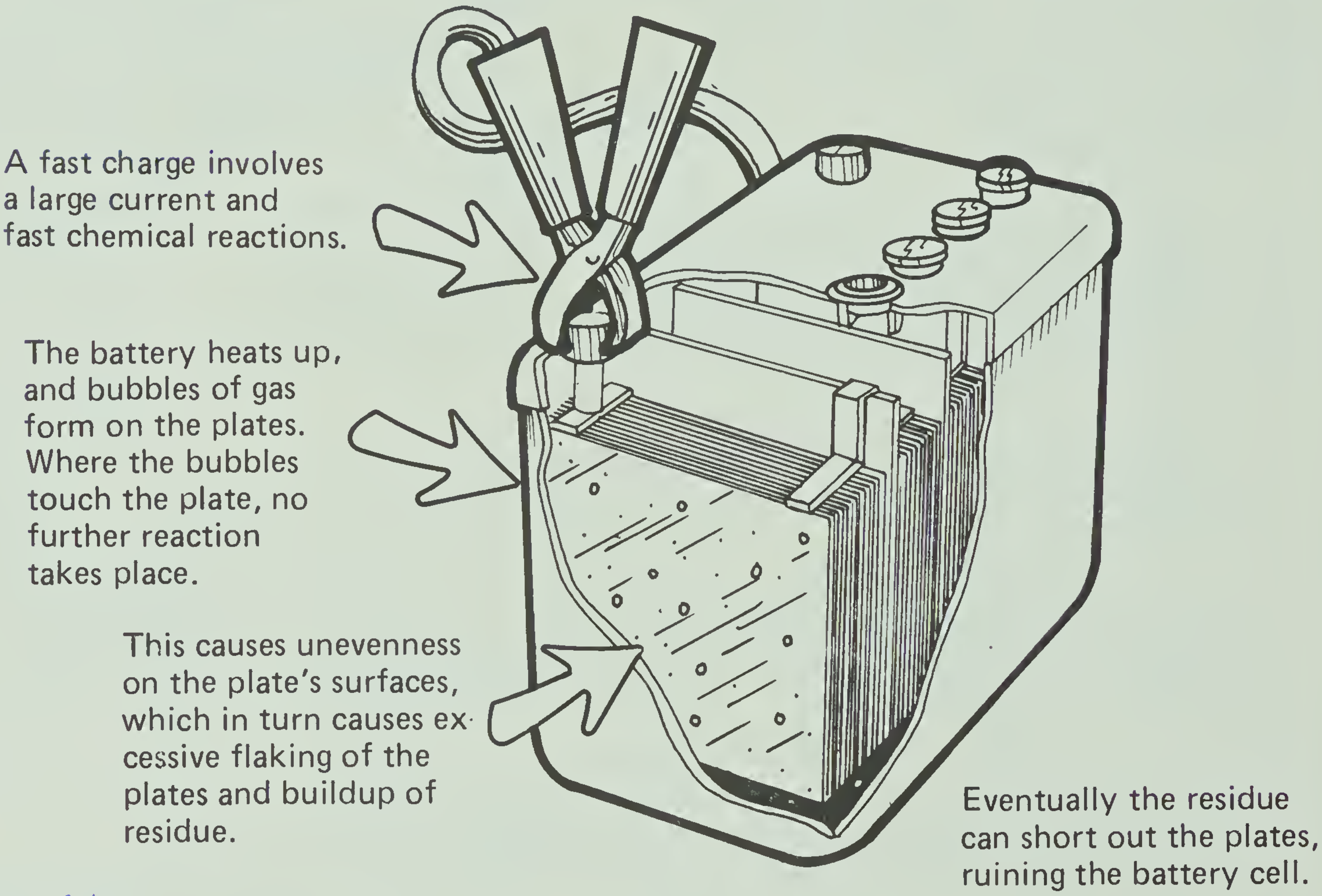


Figure 3-3

Something similar was happening when you charged your own small cell so quickly.

3-14. You can do all or any of the following: note whether the battery is starting the engine quickly; check the fluid level; see whether the battery can hold a charge; check for cracks and leaks; note whether poor connections could be responsible for reduced performance; have an expert rate the battery and check the charging rate.

☆3-14. **Suppose you noticed that your battery's warranty is about to expire. You wonder if the battery is about to fail. What are some things you could do to find out?**

ACTIVITY 4: DISTRIBUTING SPARKS

Most car engines run on gasoline. They burn a mixture of gasoline vapor and air within spaces called *cylinders*. The force of hot, expanding gases pushes against pistons inside the cylinders. The car's mechanical connections change the up-and-down motion of the pistons into the circular motion of the car's wheels.

To burn, the air—fuel mixture has to be ignited. This is done by an electric spark. The spark jumps an air gap in the spark plug, which sticks down into the cylinder.

Each up or down motion of a piston is called a *stroke*. Figure 4-1 below shows the four strokes of a car engine.

ACTIVITY EMPHASIS: An induction coil is used to produce a spark in each spark plug. The spark for each cylinder is timed and delivered by the distributor. Spark plug malfunctions are commonly due to cracks and deposits.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

FOUR–STROKE ENGINE

1. INTAKE	2. COMPRESSION	3. POWER	4. EXHAUST
Intake valve opens. Piston moves down, drawing air—fuel mixture into cylinder.	Intake valve closes. Piston moves up, compressing air—fuel mixture.	Spark plug ignites air—fuel mixture. Expanding gases drive piston downward.	Exhaust valve opens. Piston moves up, forcing burned gases out of cylinder.

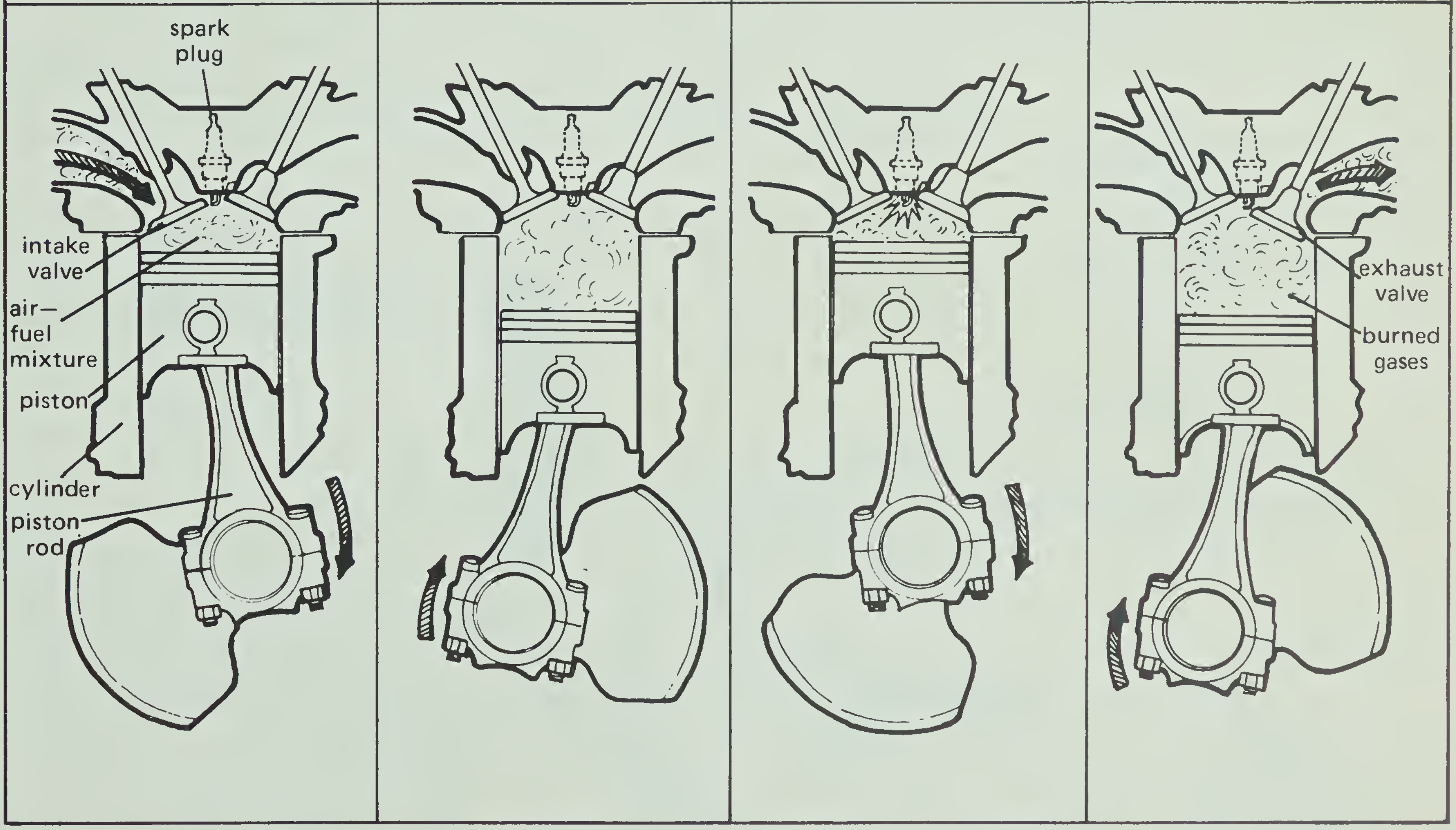


Figure 4-1

As you can see, timing is important. If a plug should ignite the gases at the wrong time, the engine would not operate smoothly. Suppose, for example, the spark plug fired before the end of the compression stroke. Then the expanding gases would push against the piston while it was still moving up. The gases would be trying to drive the crankshaft backwards.

• 4-1. What would happen if the spark plug fired on the exhaust stroke?

Look at the spark plug in Figure 4-2. Notice that the screw cap connects to the center electrode at the bottom of the plug. It does this by means of a metal path through a ceramic insulator. The side electrode is connected to the screw threads.

• 4-2. If the plug is connected in a circuit, what effect will the gap between the two electrodes have on flow of electricity? (Hint: In Activity 2, remember what was necessary for electricity to flow.)

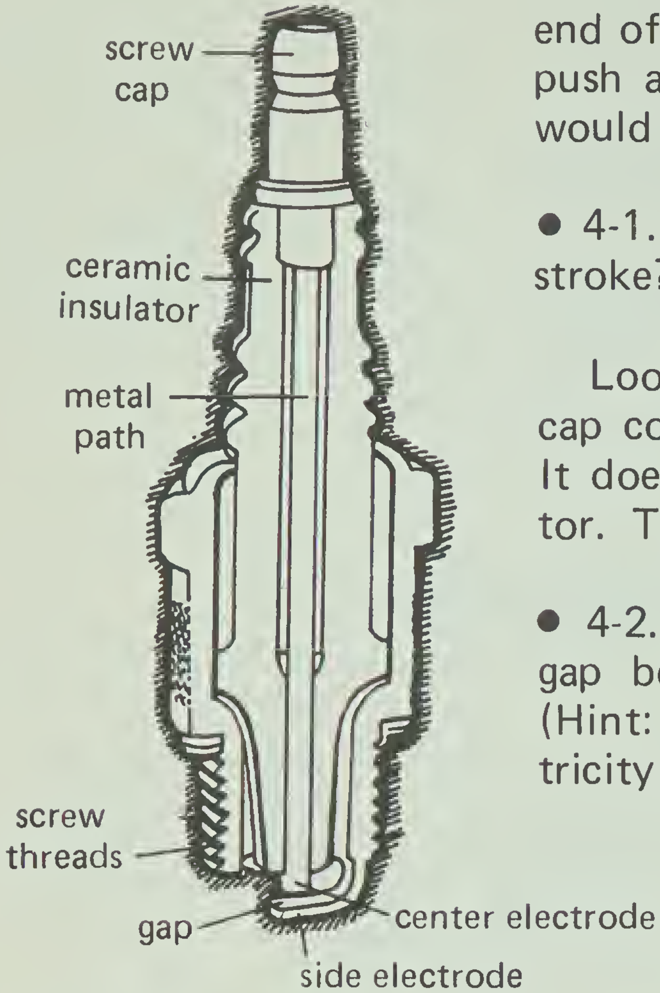


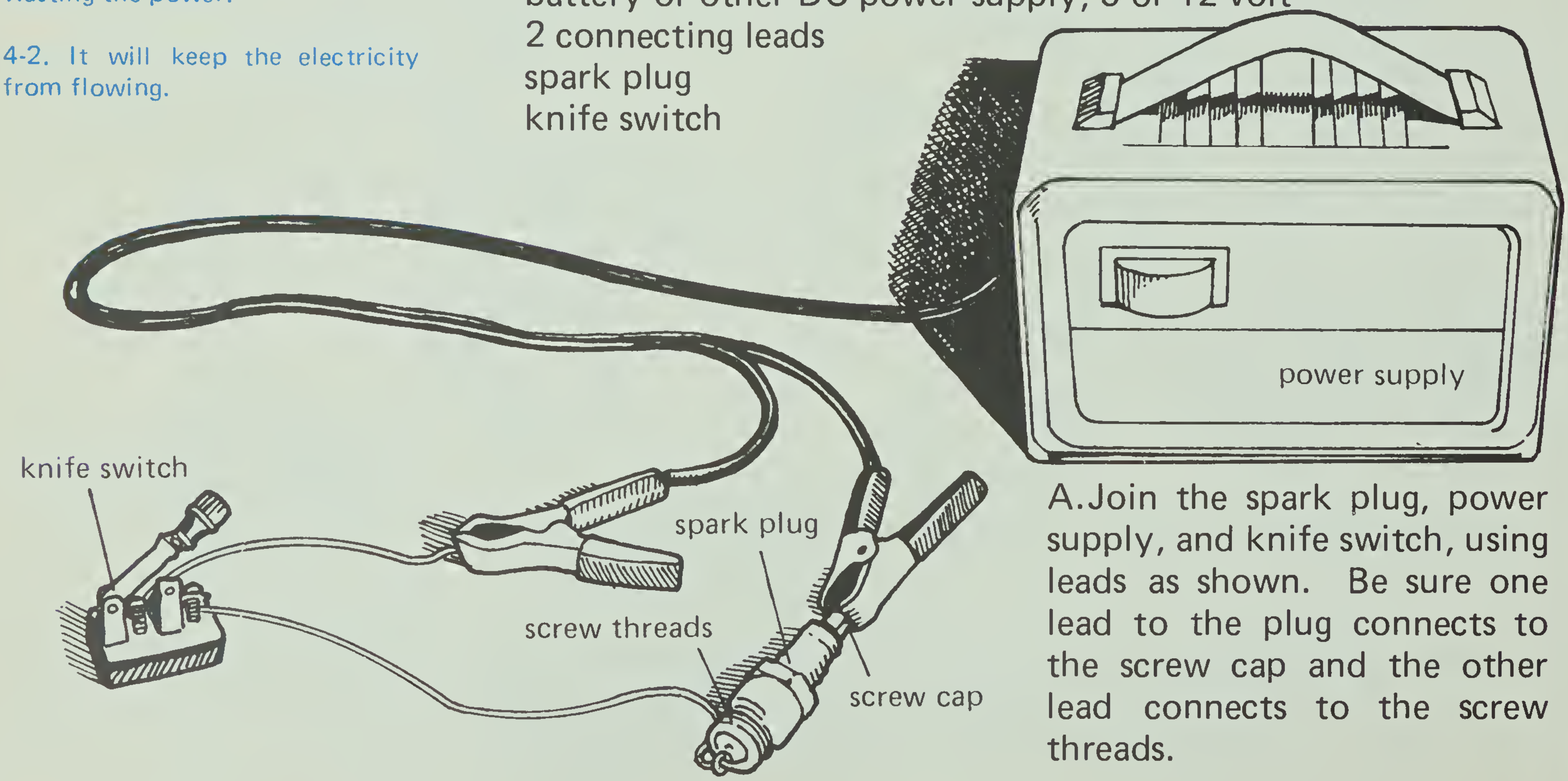
Figure 4-2

4-1. The burning gases would escape out the open exhaust valve, wasting the power.

4-2. It will keep the electricity from flowing.

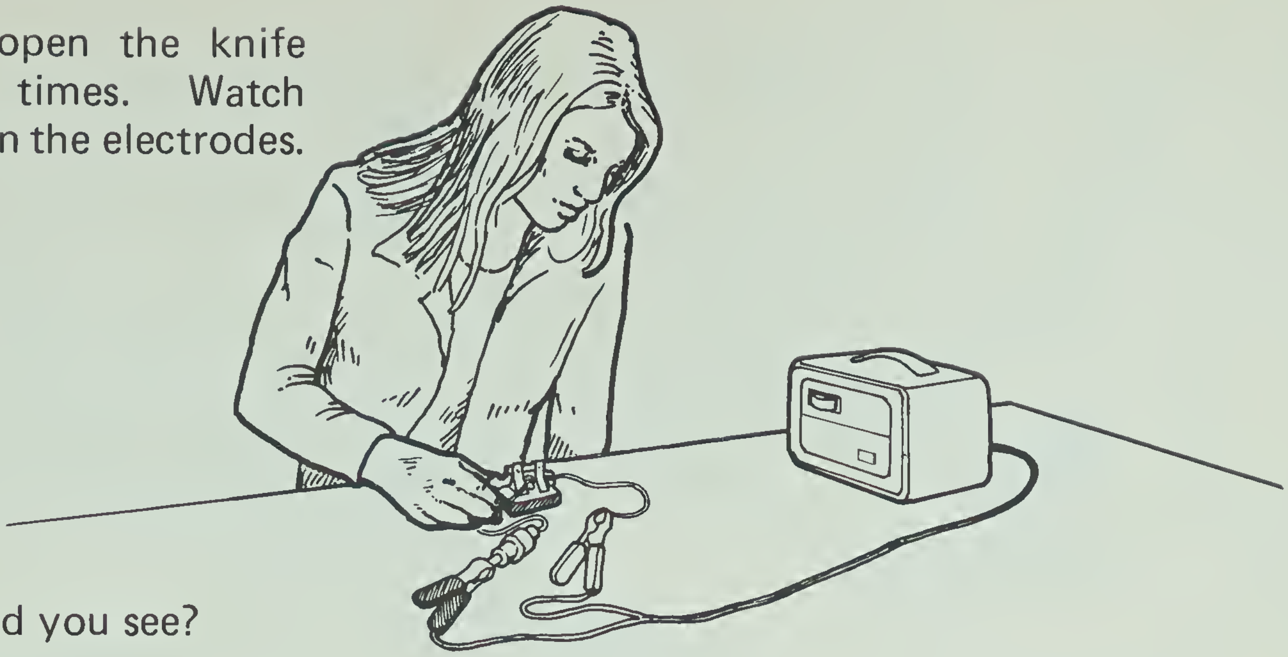
To see for yourself how a spark plug works, try a short investigation. You'll need the following materials.

battery or other DC power supply, 6 or 12 volt
2 connecting leads
spark plug
knife switch



A. Join the spark plug, power supply, and knife switch, using leads as shown. Be sure one lead to the plug connects to the screw cap and the other lead connects to the screw threads.

B. Close and open the knife switch a few times. Watch the gap between the electrodes.



● 4-3. What did you see?

4-3. Nothing

If you remembered Activity 2, you shouldn't have been surprised that nothing happened. A 6-volt or 12-volt power source doesn't supply enough voltage to send a spark across that big a gap. The air acts as an insulator.

But when a voltage thousands of times larger is used, the air becomes a conductor. Then a visible spark will jump the gap. (Electricity always needs a conducting path from one terminal of a voltage source to another.)

A car has a means of producing the large voltages needed to make a conductor of the air in the spark plug gap. One piece of needed equipment is a coil, sometimes called an *induction coil* because it induces the larger voltage. Another is a device called a *capacitor*, or *condenser*, that can store electric current temporarily.

An induction coil is like the little transformer used to run toy trains. The train transformer takes 110 volts out of the wall outlet and reduces it to a low voltage. An auto coil works the opposite way. It takes a low voltage and raises it very high — up to 30,000 volts.

Both the toy transformer and the induction coil operate on the same principle. Two separate coils of wire, a primary and a secondary, are wound around an iron core (Figure 4-3). If the electricity flowing through the primary is changed — turned on or off — it induces a voltage across the secondary. And when the secondary contains a large number of turns of wire compared to the primary, the secondary voltage is very large.

See how these added devices work as you continue the investigation. You'll need some additional equipment.

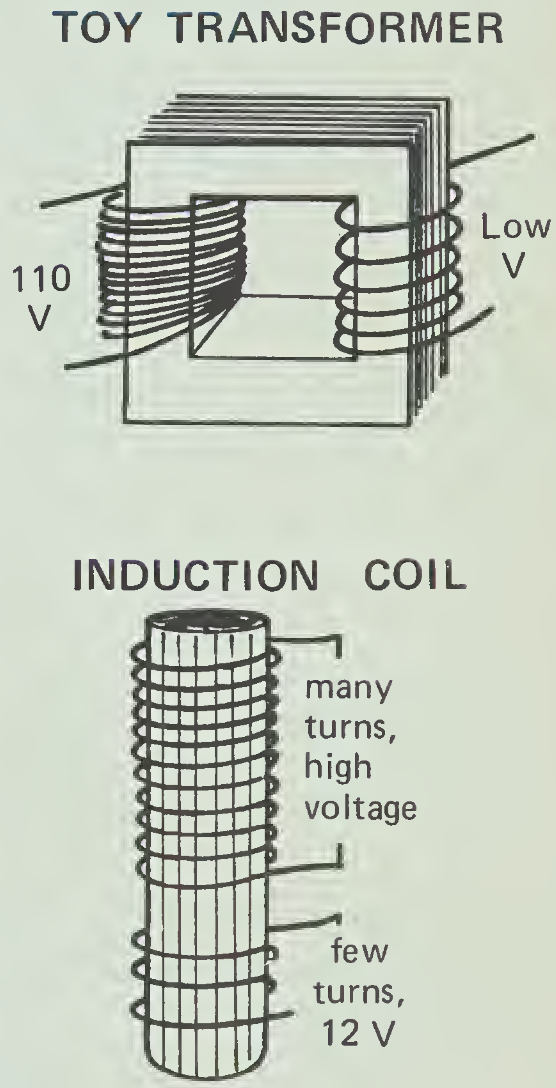
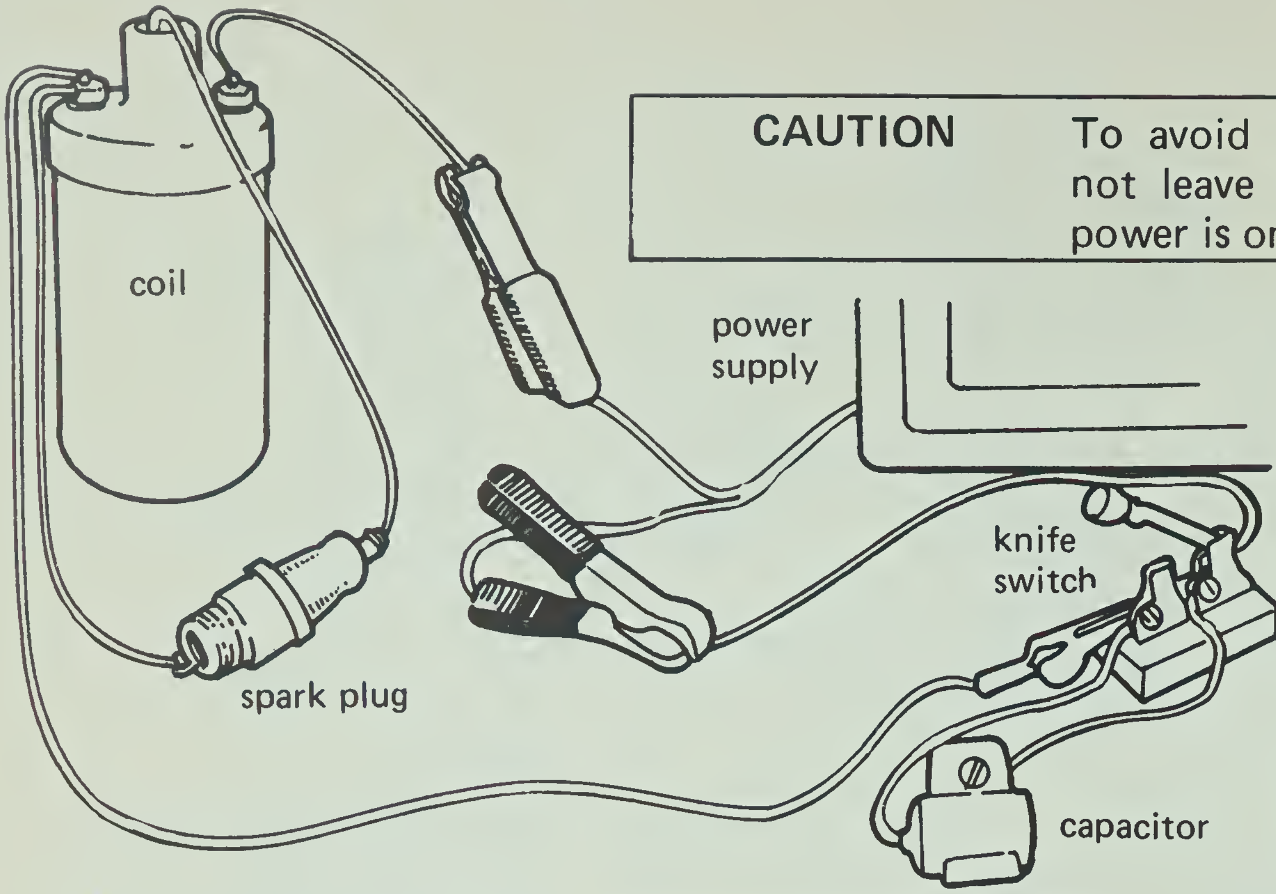


Figure 4-3

capacitor (condenser)
induction coil
5 connecting leads



CAUTION	To avoid overheating the coil, do not leave the switch closed when power is on.

C. Connect the capacitor to each terminal of the knife switch. Then add the coil and spark plug to the circuit, as shown.

D. While watching the spark gap, close the switch. Then open the switch.

4-4. Nothing happened when the switch was closed, but a spark jumped when the switch was opened again.

The high-voltage current of the secondary circuit is induced in the coil by the rapid collapse of the magnetic field surrounding the low-voltage current of the primary circuit.

- 4-4. What did you see?

A very high voltage current is needed to produce the spark. This current is induced in the coil when the circuit is broken. In your investigation, you broke the circuit by opening the knife switch. In the ignition system of a car, this job is done by a set of breaker points.

The breaker points, together with the capacitor, are located in the lower part of the distributor. Look at Figure 4-4 below.

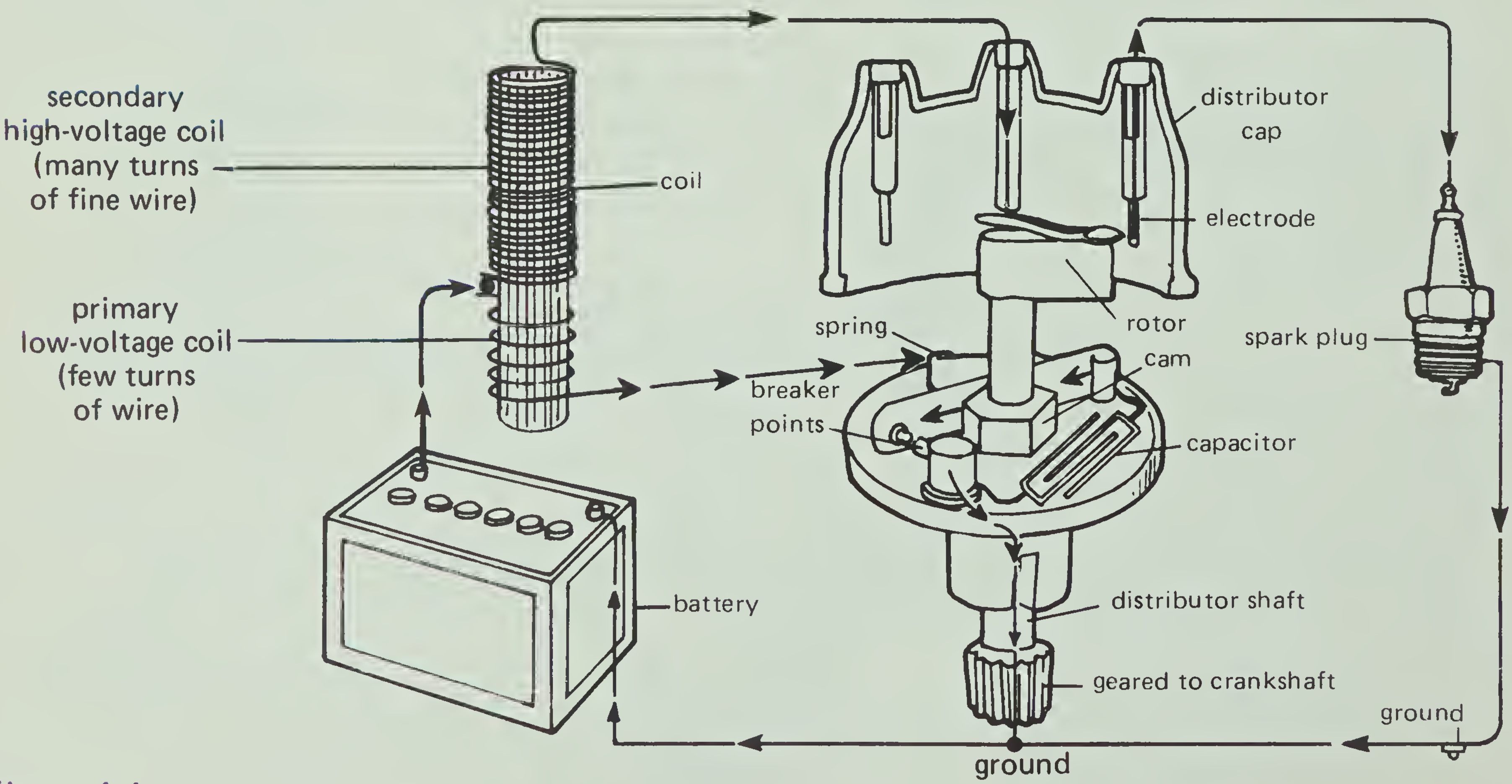


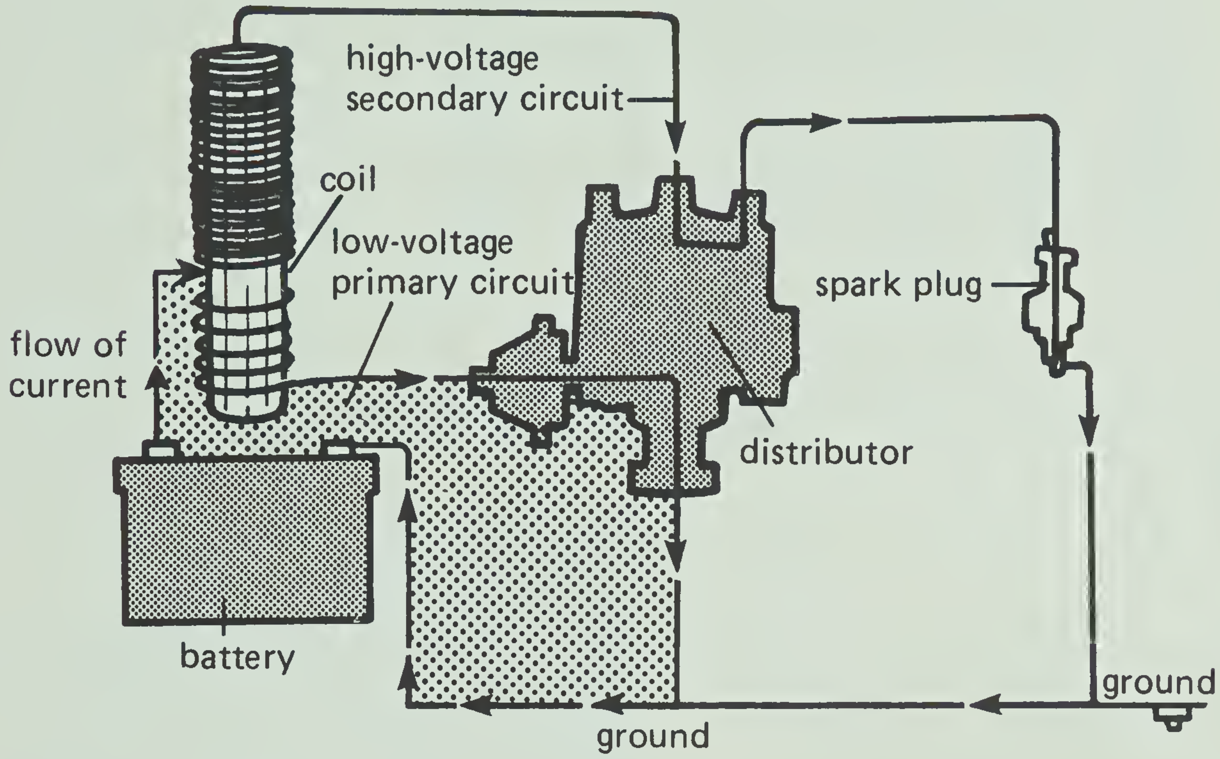
Figure 4-4

The breaker points are opened and closed by an arm and cam arrangement. The breaker cam is on the distributor shaft, which turns whenever the engine is turning over. There are as many lobes (edges) on the cam as there are cylinders in the engine. So each revolution — complete turn — of the distributor shaft results in a separate pulsation and spark for each cylinder.

Some high-performance engines have distributors with two sets of points that operate alternately.

The distributor shaft turns in a 1 to 2 ratio with the crankshaft.

You may have noticed in Figure 4-4 (page 18) that the ignition system contains two circuits. The *primary* circuit is low voltage. Its job is to induce pulsations of current in the coil. The *secondary* circuit is high voltage. Its job is to deliver sparks to the cylinders.



● 4-5. In which circuit or circuits — primary, secondary, or both — does the coil participate?

4-5. In both

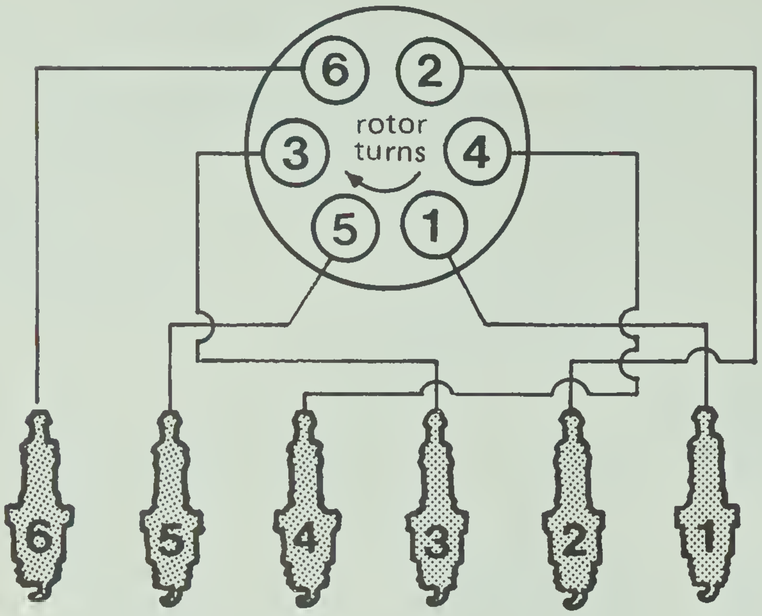
Look at Figure 4-4 (page 18) again. Above the breaker-point assembly on the distributor shaft is the rotor. As the shaft turns, the rotor spins. Surges of high-voltage current travel down the rotor arm and jump across to the electrodes spaced around the edges of the distributor cap. There is one electrode with a lead for each spark plug. In a six-cylinder car, there will be six electrodes evenly spaced around the distributor cap. And there will be six lobes on the cam. Each time the breaker cam forces the points open, the rotor arm is opposite an electrode. Thus, a surge of current travels to a spark plug.

● 4-6. What path does the high-voltage current take in going from the coil to the spark plug? (Refer to Figure 4-4.)

4-6. Coil to center of distributor cap to rotor arm to electrode to spark plug

The distributor supplies current to the spark plugs at regularly spaced intervals, not all at once. Each plug has a different time to fire. The engine runs more smoothly if the power strokes are spaced over the firing cycle.

FIRING ORDER FOR A SIX–CYLINDER ENGINE



To determine firing order, follow the curved arrow around the circle: 1–5–3–6–2–4.

4-7. The firing sequence would be thrown off. The engine would operate roughly and might even be damaged.

4-8. A2, B4, C3, D1, E5, F6

● 4-7. What do you think might happen if the wires between the distributor and two spark plugs got switched?

☆ **4-8. Match the ignition-system part with its function.**

Part	**Function**
A. Distributor	**1. igniting air–fuel mixture**
B. Coil	**2. both the timing and the distribution of current surges**
C. Breaker points	**3. opening and closing to create current surges**
D. Spark plugs	**4. direct source of high voltage**
E. Capacitor	**5. helping coil by storing current temporarily**
F. Rotor	**6. passing high-voltage surge to proper plug contact**

In operation, the breaker points may have to open hundreds of times a second. The exact number depends on engine speed. Eventually, the breaker points wear out. Then repairs are needed.

In addition to the conventional coil–capacitor–breaker point system, there are two other basic ignition systems used on gasoline-powered American passenger cars. Both use a transistor to pass an electrical impulse on to the coil. Thus, they are sometimes referred to as *solid-state*, or *electronic*, ignitions. One of these two systems still uses breaker points. But with a transistor, less current is used, so the points do not wear out as fast.

The ignition systems on new American cars use no breaker points. Instead, a rotating magnetic field is used to pass impulses on to a coil. Without troublesome points opening and closing, maintenance is reduced.

☆ **4-9. The ignition systems on new American cars**
A. use no breaker points.
B. do not use coils.
C. are the same as those on older American cars.

4-9. A

When someone says that an engine is "missing," it means that at least one of the cylinders in the engine isn't firing properly when its turn comes. Often, the problem involves the spark plug. Figure 4-5 below shows some possible things that could be wrong.

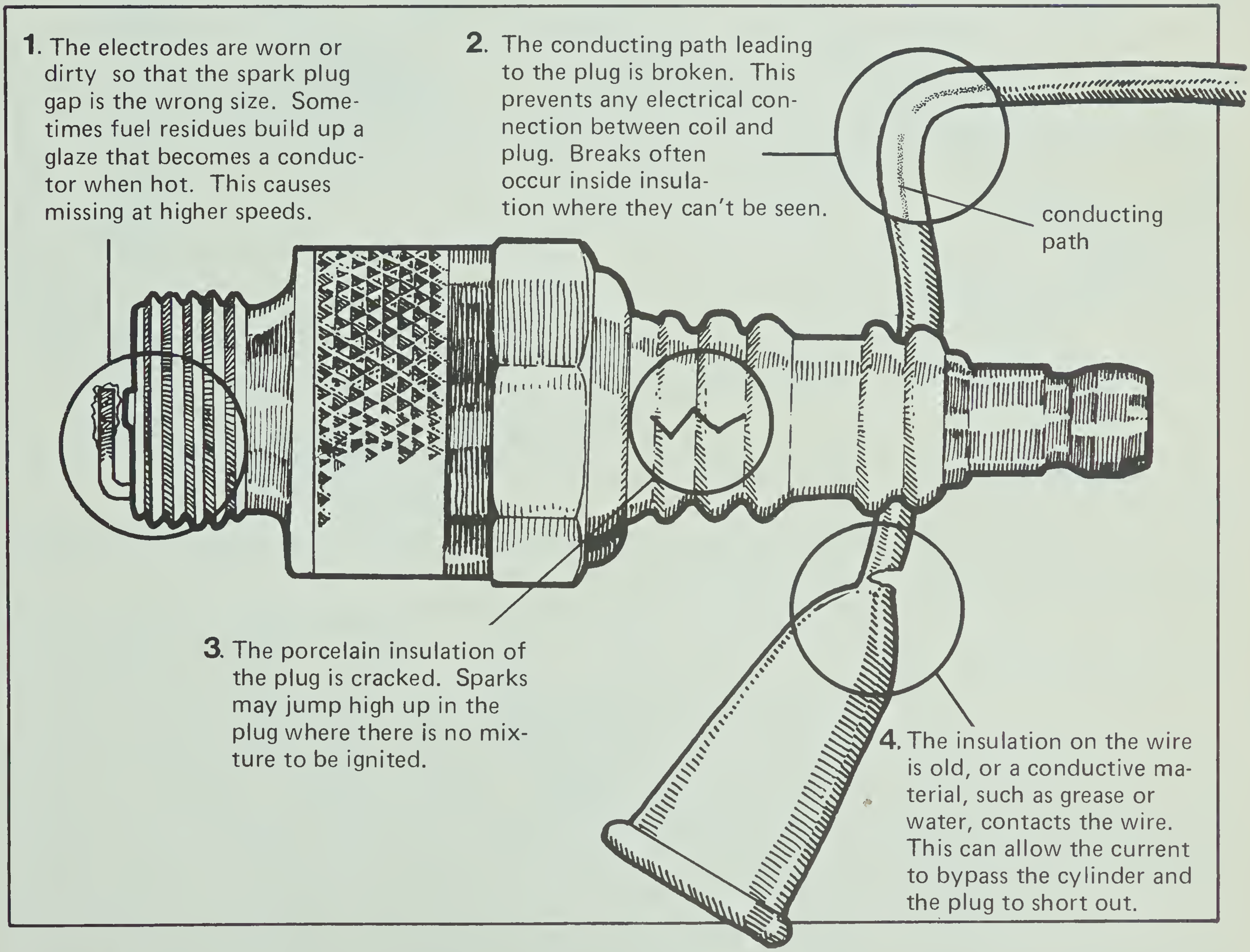


Figure 4-5

Many service stations have special instruments that can show which plug is not firing. But you can determine that by yourself. Figure 4-6 below shows the way it's done.

1. Let the engine idle. Disconnect one insulated connector from its spark plug. (Caution: Don't touch anything but the insulation, and don't rest your body or hands on the car. You don't want to be part of the circuit!) Pull on the connector, not the wire, which might break loose. Notice the engine sound. If it does not change quality when you disconnect the plug, that plug may be the bad one.

2. Keep testing until you find the cylinder that's missing. Then hold the disconnected plug connector close to the engine, but not touching it. Does a spark regularly jump to the block from the connector? If so, the disconnected plug is faulty.

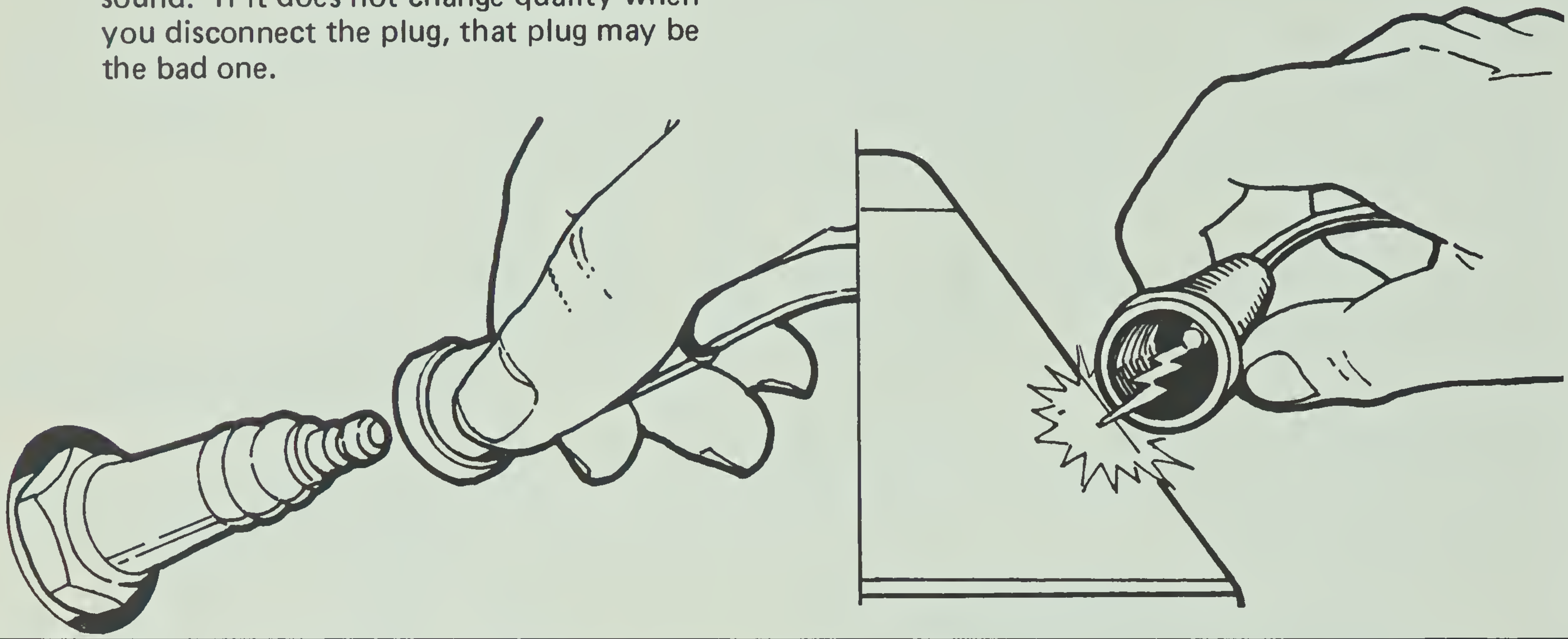


Figure 4-6

4-10. You would be shutting down another cylinder, causing a second kind of miss.

4-11. That it's probably in the wire or distributor, not in the plug

4-12. The gap is too wide for the voltage. The spark can't jump it.

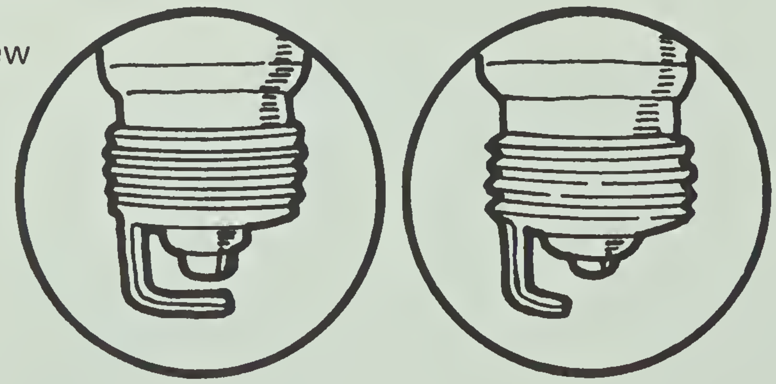
4-13. Disconnect the plug wires in turn. The one that doesn't change the engine sound shows the cylinder at fault. Then check the sparking of that wire against the engine block to see whether or not the problem is in the plug.

● 4-10. Why would the engine sound change if you disconnected a good plug?

● 4-11. Suppose you don't see a spark jumping regularly. What does that indicate about the source of the trouble?

☆ **4-12. Look at the two spark plugs shown below. What might be causing Plug B not to fire?**

Plug A. New



Plug B. After 15,000 km

☆ **4-13. Suppose your car's engine was missing badly. How would you find out whether the problem was a bad spark plug?**

ACTIVITY 5: KEEPING COOL

What's a "hot" car? It may be one that's very fast or one that's been stolen or one that's not air conditioned. Or it may be a car with a faulty cooling system.

The air—fuel mixture in an automobile engine burns at a temperature of about 1100°C. A lot of heat energy is released. Figure 5-1 below shows where the energy goes.

ACTIVITY EMPHASIS: Cooling systems keep engines from overheating. To help the systems function properly, most liquid-cooled systems are pressurized, use antifreeze both winter and summer, and include an overflow reservoir. The thermostat uses feedback control in maintaining proper temperature.

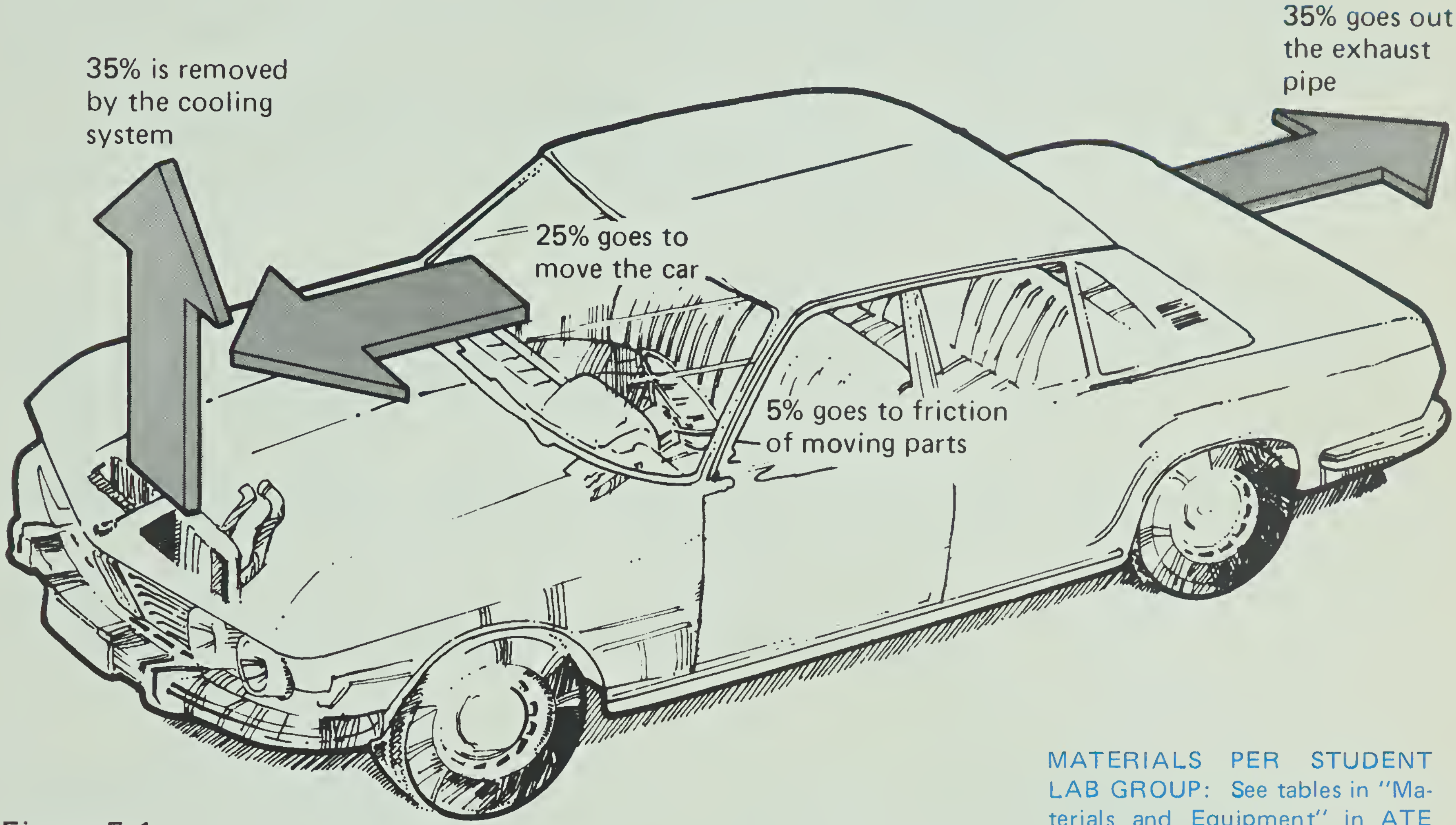


Figure 5-1

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

• 5-1. How much heat energy must be removed by the cooling system? (See Figure 5-1.)

5-1. Heat energy equal to 35% of the energy released by combustion

There are two types of automobile engines – air cooled and liquid cooled. An air-cooled engine usually has cooling fins of metal. These fins allow more of the engine's surface to be in contact with the air. A liquid-cooled engine has a radiator. The radiator receives heated liquid from the engine block and returns cooled liquid to the engine block. An engine of either kind usually has a fan to help the radiator give its heat to the air. Figure 5-2 (page 24) shows how the system in a liquid-cooled engine works.

The air-cooled engine may have a "shroud" to channel air better around the fins. Then the fins can't be seen. Some liquid-cooled engines also have shrouds between the radiator and the engine block.

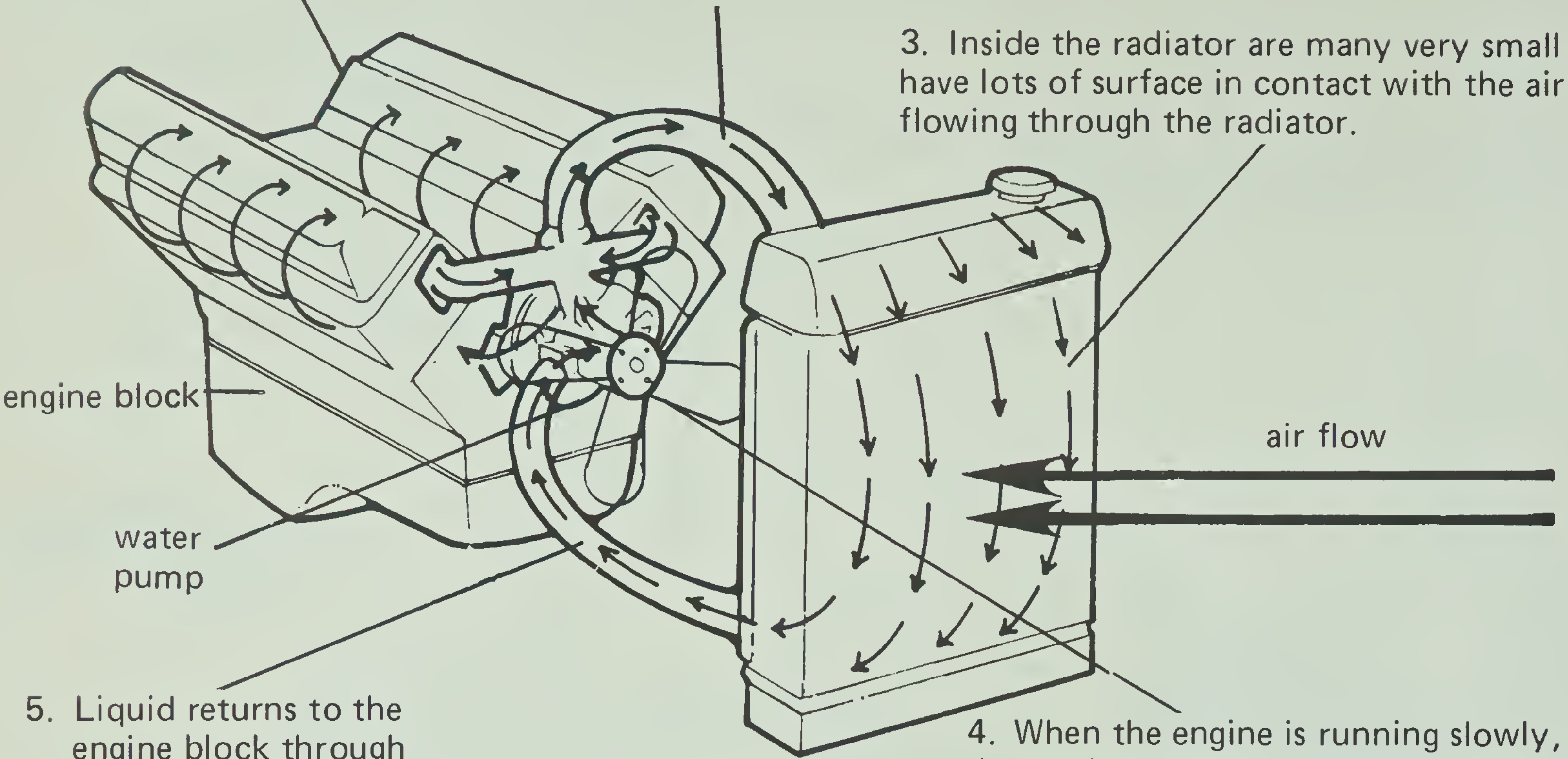
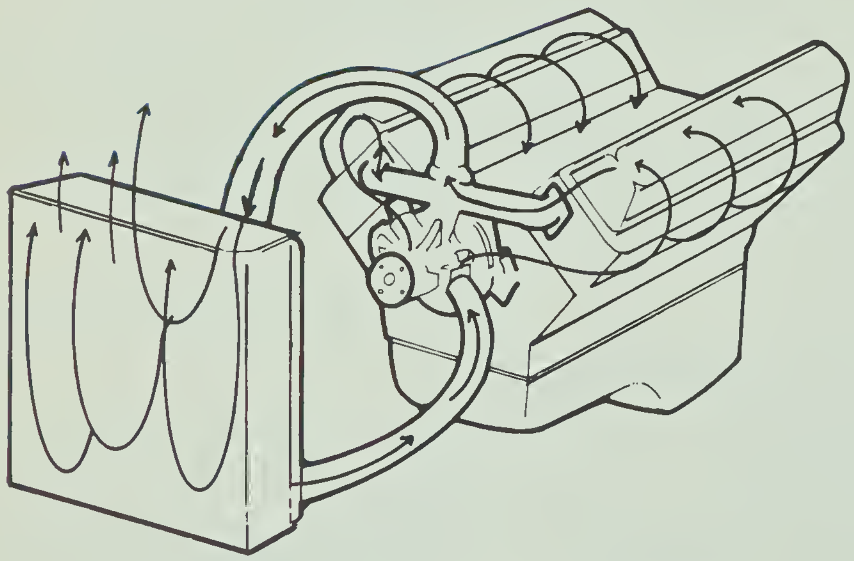


Figure 5-2

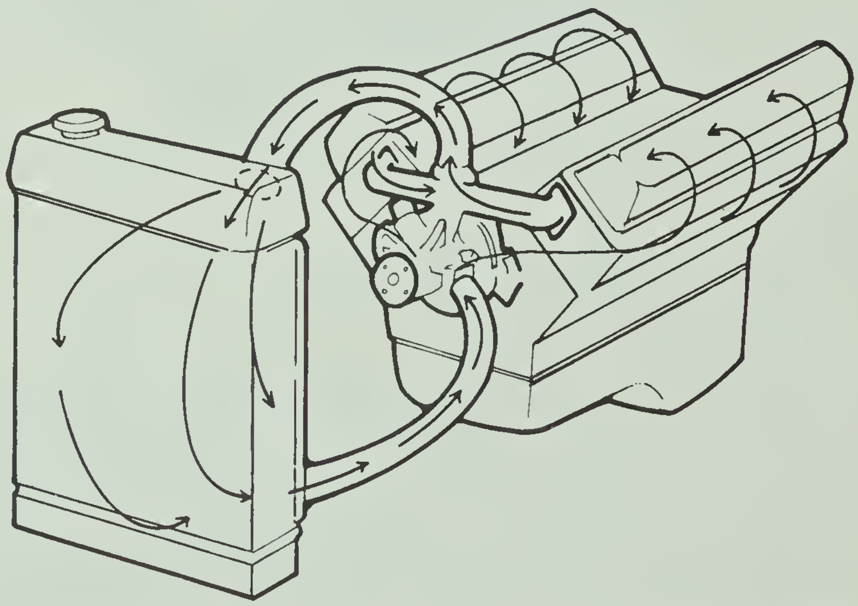
5-2. Down through the radiator through the lower hose to the block, up through the block, through the upper hose to the top of the radiator

☆ **5-2. What is the direction of liquid flow through the radiator, the hoses, and the engine block of a cooling system?**

Water that's not under pressure will boil at about 100°C. Liquid in the engine block will easily reach this temperature.



If the radiator were open to the air, the liquid would soon boil away. And the engine would burn up!



When the cooling system is closed and pressurized, the liquid can get much hotter without boiling. If the pressure becomes too great, a relief valve in the radiator cap will open, releasing some liquid.

☆ **5-3. What is an advantage of pressurizing a cooling system?**

5-3. The liquid can circulate at a higher temperature and not boil away.

The coolant in the system is usually more than just water. Antifreeze is generally added to the water. This has two effects. It lowers the freezing point, and it raises the boiling point. This allows the engine to operate in wide extremes of temperature.

For instance, a mixture of 50% water and 50% antifreeze has a freezing point of −29°C. This same mixture also has a boiling point in a typical pressurized system of about 129°C.

☆ **5-4. Why do experts recommend putting antifreeze in a car even when there's no danger that the temperature will drop to freezing?**

5-4. The higher boiling point permits the cooling system to operate at higher temperatures without loss of coolant.

Engines sometimes overheat. This happens especially in hot weather. The four main reasons for overheating are shown in Figure 5-3 below.

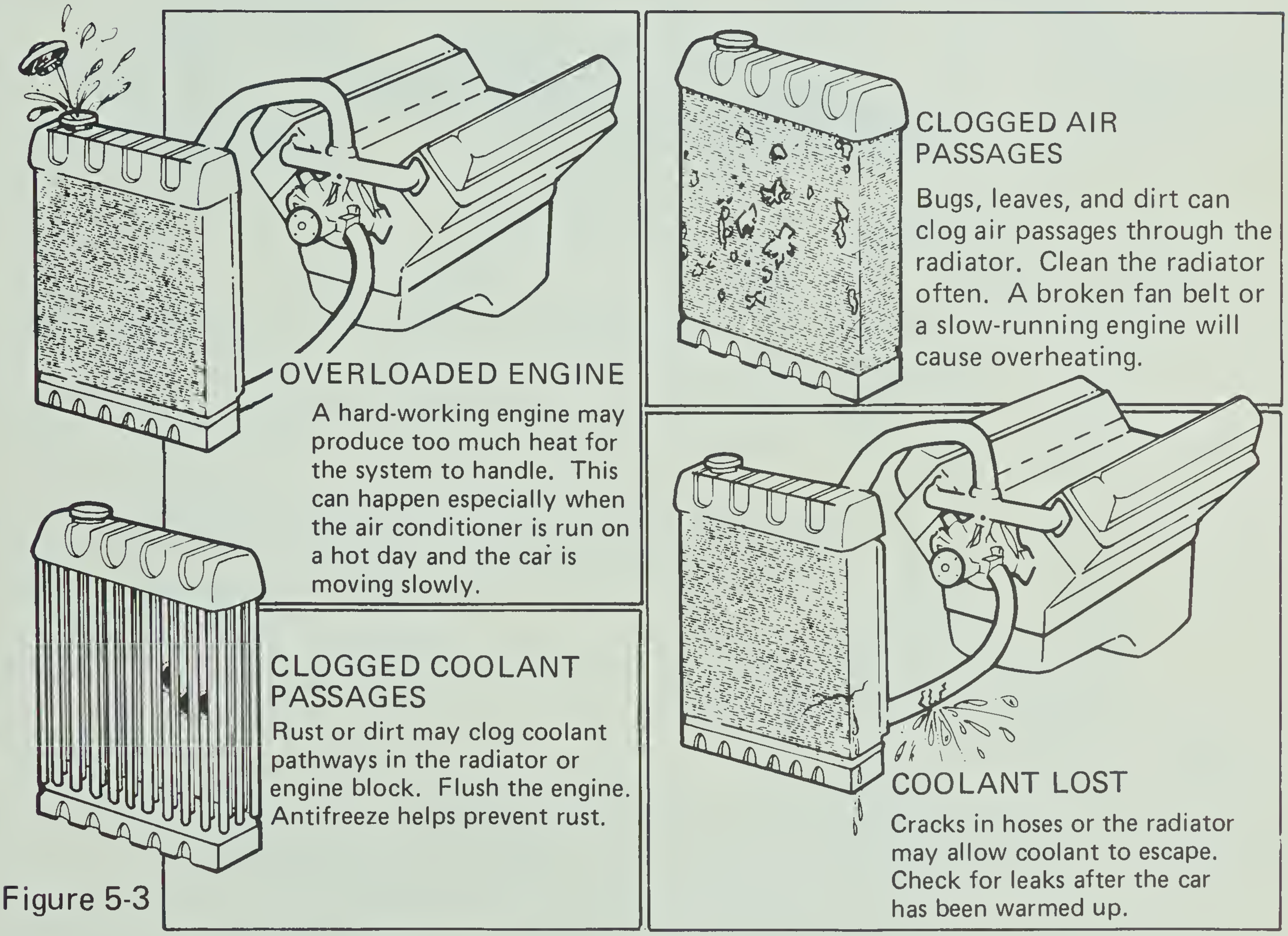


Figure 5-3

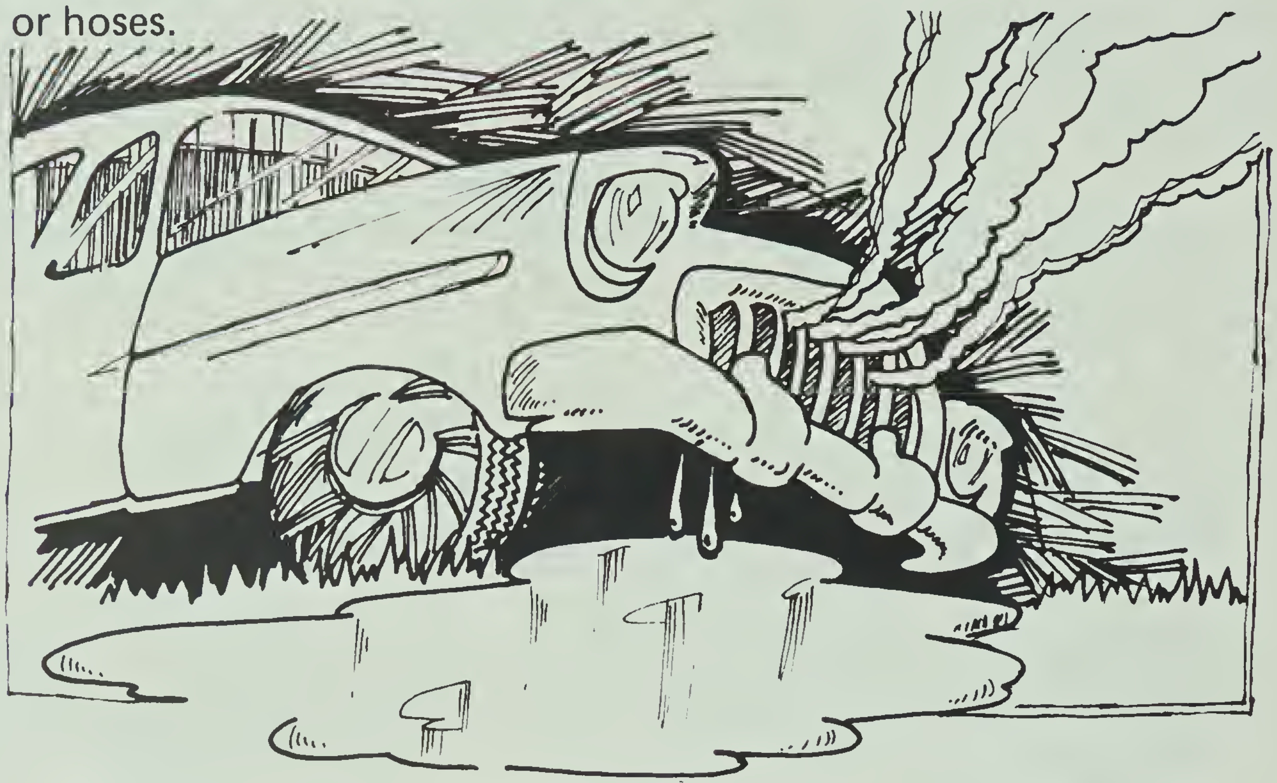
Use extreme care in opening the cap on a pressurized radiator when the engine is hot. You can get a severe burn from hot liquid.

5-5. Overloaded engine; clogged air passages; clogged coolant passages; coolant lost

☆ 5-5. List four major causes of engine overheating.

Consider what happens when a car is stopped after it has run for a while. When the engine is shut off, the flow of air through the radiator stops. The circulation of coolant stops too. But the engine block is still hot. It continues to heat the coolant. The uncirculated coolant may reach a much higher temperature than it did when the engine was running.

This can cause coolant to escape. It may escape through the pressure relief valve or through any tiny cracks in the radiator or hoses.



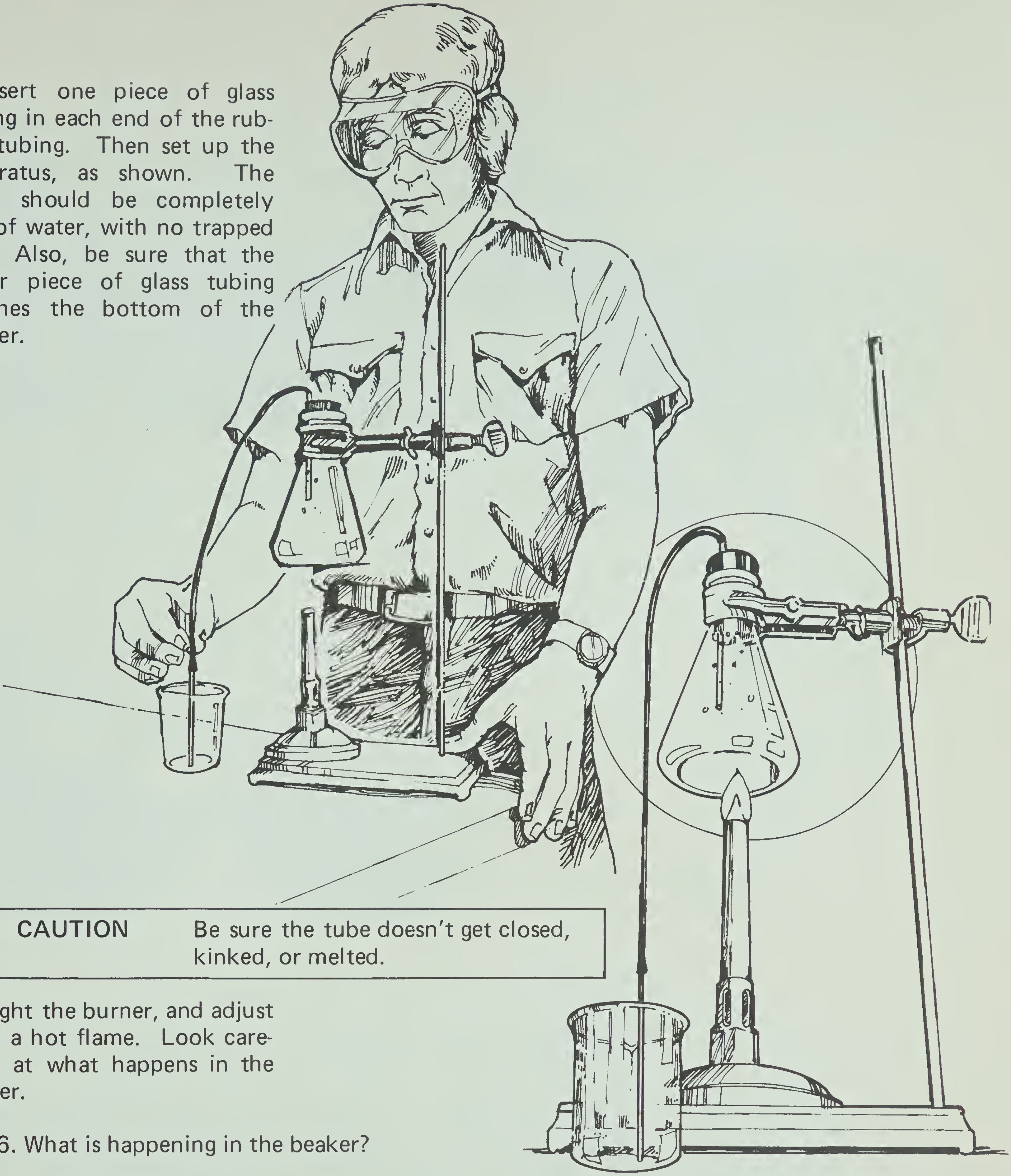
There's a way to cut down on this kind of coolant loss. Often engine designers add an overflow reserve tank, or reservoir, to the closed cooling system. It works on the principle that coolant, like most things, expands when heated and contracts when cooled.

When it is heated by the hot engine block, the coolant expands. Some of it gets forced into a reservoir. When the engine cools, the coolant contracts. The excess is drawn back to the radiator.

To see how this works, try an investigation. You'll need the following equipment.

- safety goggles
- 250-ml flask with one-hole stopper
- 2 pieces of glass tubing, 15 cm long, to fit stopper
- 40 cm of rubber tubing to fit glass tubing
- 100-ml beaker or small jar
- Bunsen burner
- ring stand with clamp
- safety matches

A. Insert one piece of glass tubing in each end of the rubber tubing. Then set up the apparatus, as shown. The flask should be completely full of water, with no trapped air. Also, be sure that the lower piece of glass tubing touches the bottom of the beaker.



CAUTION	Be sure the tube doesn't get closed, kinked, or melted.

B. Light the burner, and adjust it to a hot flame. Look carefully at what happens in the beaker.

- 5-6. What is happening in the beaker?

C. Turn off the burner before the beaker gets three-fourths full. Let the flask cool for a while. Watch what happens to the water in the beaker.

5-6. Water flows from the flask through the tube and into the beaker.

5-7. The water flows back into the flask.

● 5-7. What happens to the water as the flask cools?

The water returned to the flask because of pressure differences. The air pressure inside the cooling flask was less than the atmospheric pressure on the water surface in the beaker.

Your flask is like the cooling system passages in some engines. The beaker is like a reservoir. And the rubber stopper in the flask functions like the safety valve in a radiator cap. It could pop out if the pressure got too high. Look at Figure 5-4 below.

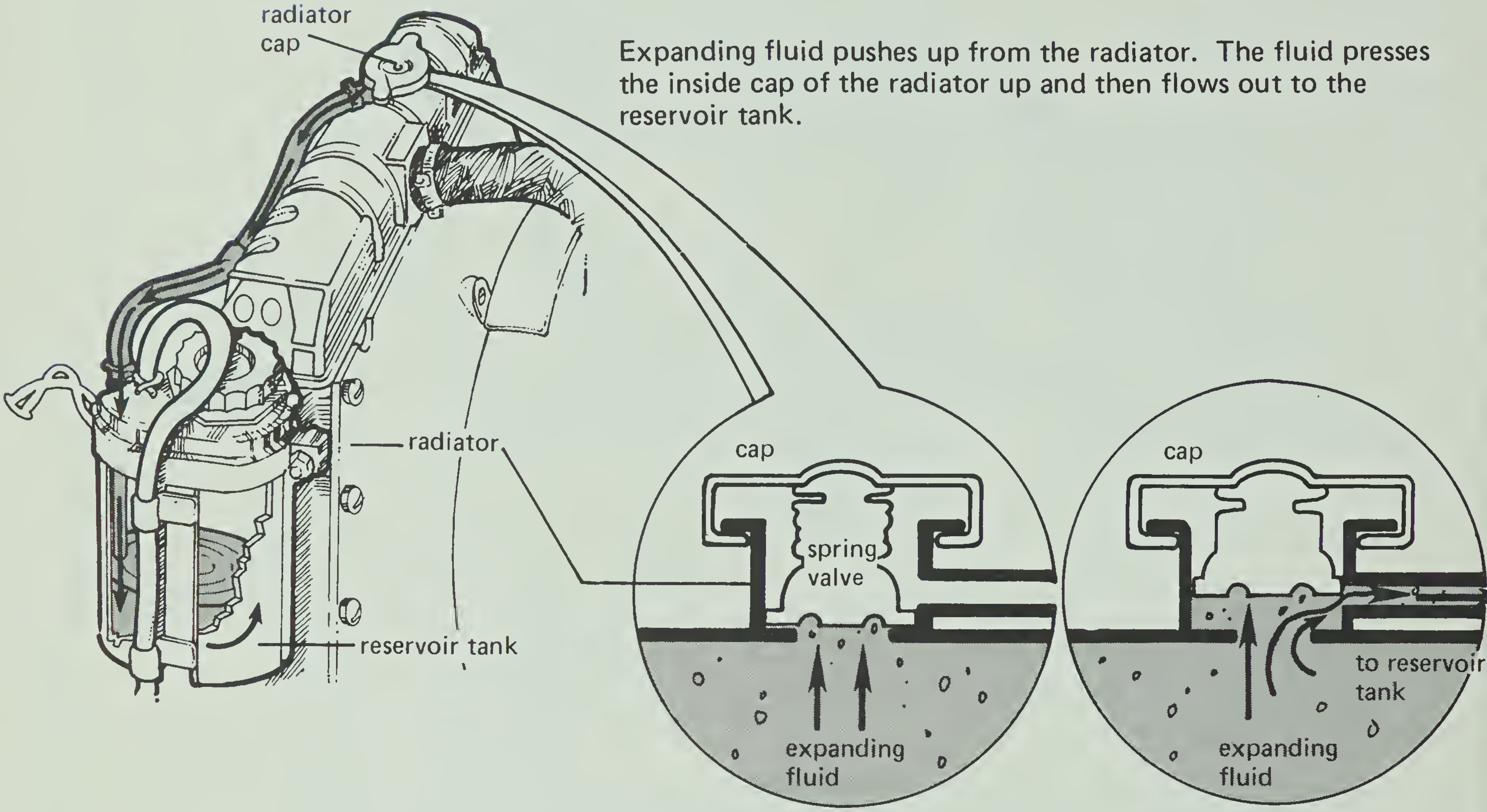


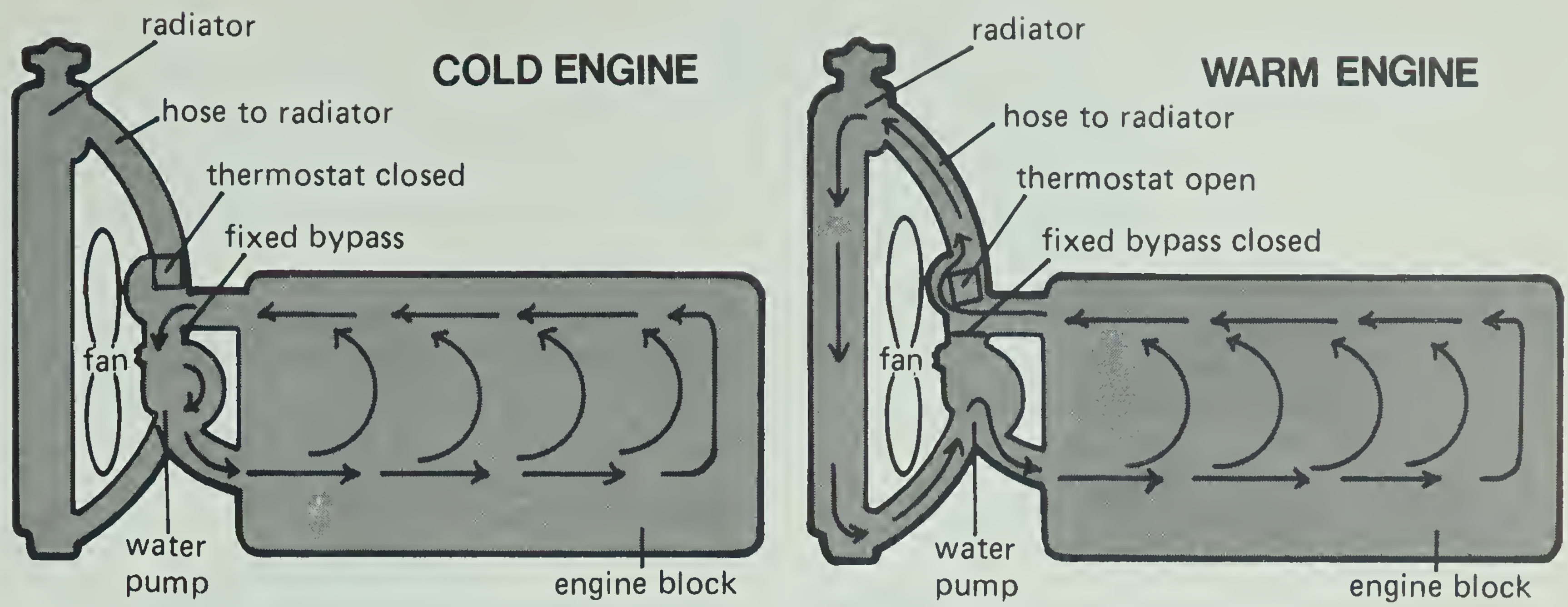
Figure 5-4

5-8. The pressure inside the radiator is less than the pressure on the liquid in the overflow tank, so the liquid is forced back to the radiator.

If you decided to use the optional thermostat activity described in "Advance Preparations" for Activity 5, this would be the place to make it available.

☆ **5-8. What could cause the fluid to return to the radiator from the overflow reserve tank when the radiator cools?**

Until a car engine warms up, it always performs poorly. But an efficient cooling system will prevent the buildup of heat in the engine. How can the cooling system allow the engine to warm up quickly in cold weather but still keep it from overheating in hot weather? The answer is a thermostat. The thermostat is usually placed in the upper hose outlet from the engine to the radiator. The operation of a thermostat is shown in Figure 5-5 (page 29).



When the system is cold, the thermostat shuts off the flow of liquid from the engine block to the radiator. But the liquid still circulates through the engine block.

As the liquid temperature rises, it heats the thermostat. The thermostat gradually opens. Liquid flows to the radiator.

Figure 5-5

The thermostat controls the circulation of liquid to the radiator by feedback. The feedback loop in Figure 5-6 below shows how it works.

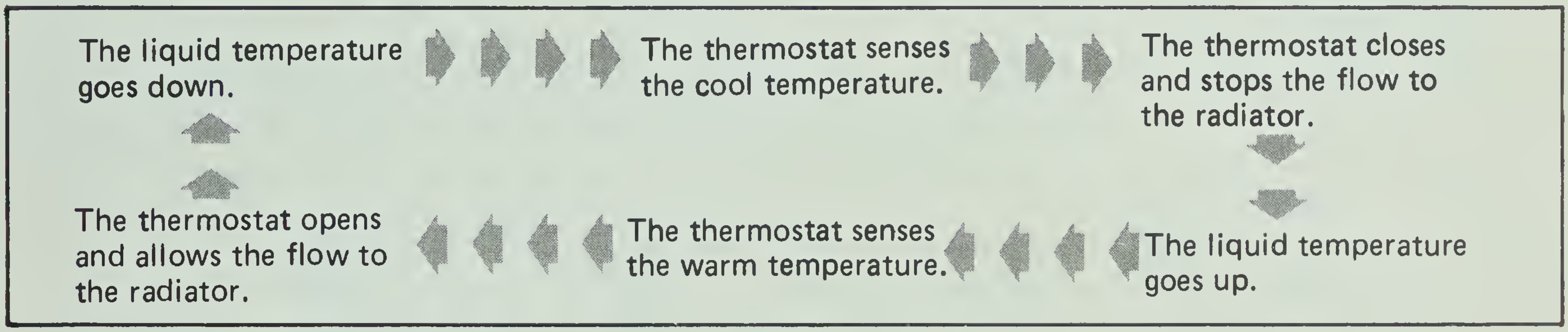


Figure 5-6

If this is the first time you've studied feedback control, don't worry if you don't see how it applies to things other than thermostat control. You will read about it again in other mini-courses. However, if you don't feel comfortable about your understanding of it now, you may want to take a look at "Resource Unit 13: Systems and Feedback." It describes feedback control in detail.

If an automobile thermostat is available, you may want to put it in hot and cold water to see how it opens and closes.

☆ **5-9. How do liquid-cooled engines use feedback to regulate engine operating temperatures?**

5-9. The liquid temperature determines the temperature of the thermostat. A warmer thermostat opens up the passage for greater circulation of liquid to the radiator. This cools the liquid. Liquid cools the thermostat, which closes the passage, restricting circulation and causing the liquid to warm up.

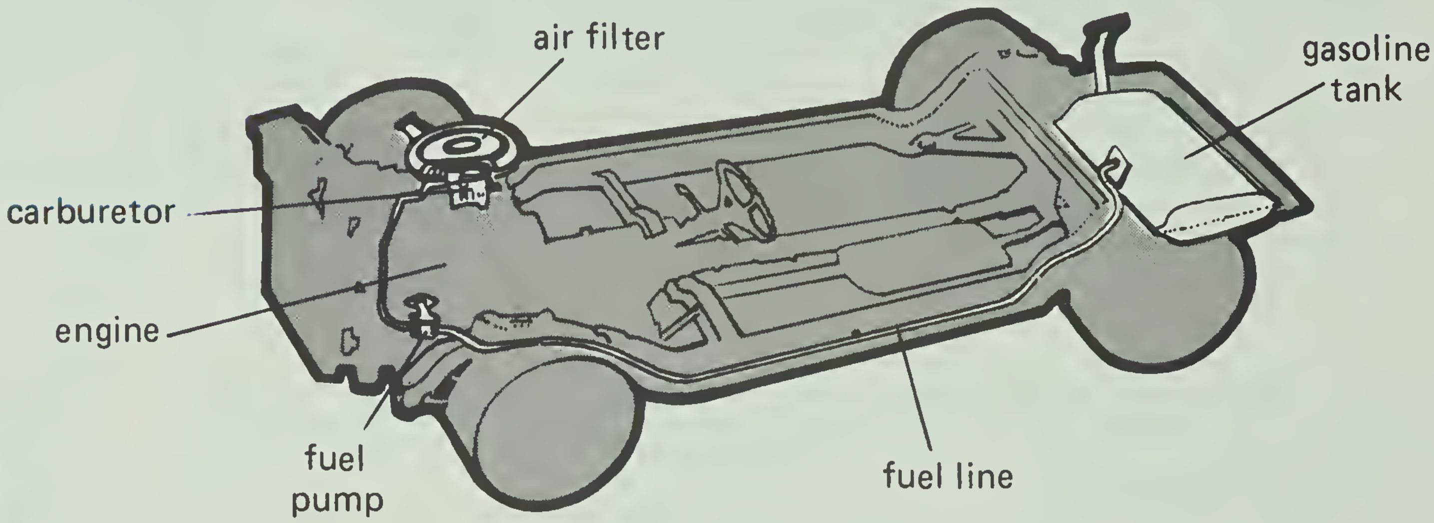
ACTIVITY EMPHASIS: The carburetor combines the proper amounts of fuel and air for burning in the cylinders. The choke controls the amount of air intake, making the mixture rich (little air) or lean (little fuel).

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

ACTIVITY 6: FUELING AROUND

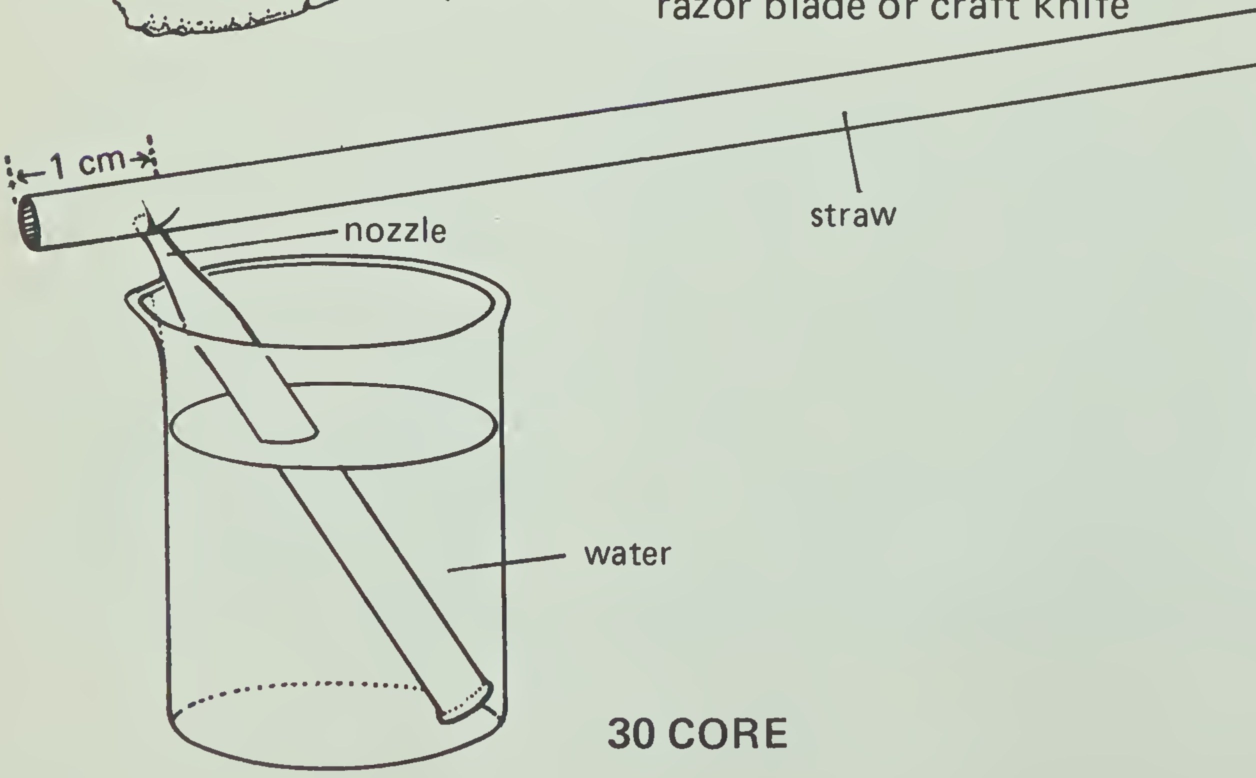
If you're going to operate a car, you have to have money to burn because cars burn gasoline and gasoline costs money. The cost of fuel is a big part of the expense of running a car. So, you'll want to be sure that your gasoline money isn't totally exhausted!

Gasoline burns best when it's been vaporized and mixed with air. This job is done by the carburetor. Most gasoline-burning cars have a carburetor that sits on top of the engine just under the air filter.



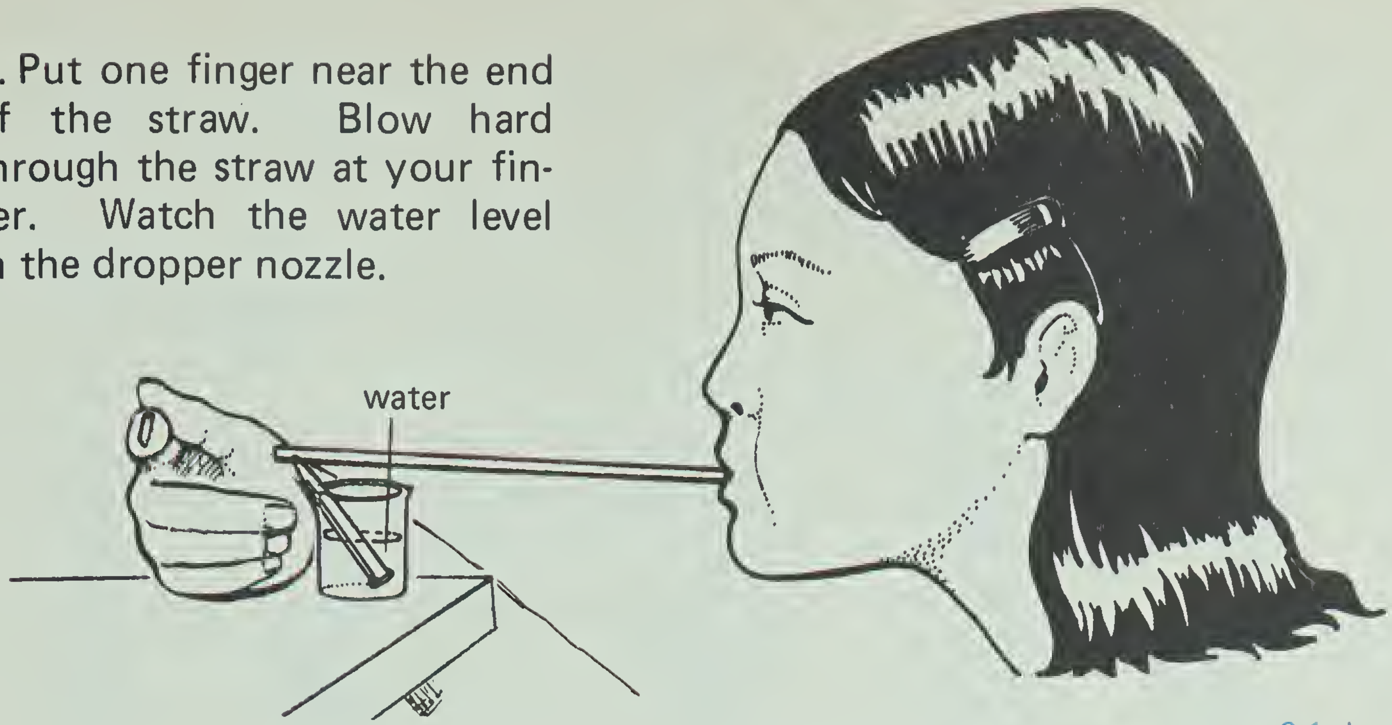
The carburetor mixes air and fuel in a fairly simple way. To see how, you can build a model air—fuel mixer. Get the following materials.

plastic drinking straw
dropper nozzle
50-ml beaker or other small container
razor blade or craft knife



A. Fill the beaker with water. Near one end of the plastic straw, make a small X-shaped cut. The center of the cut should be about 1 cm from the end of the straw. The legs of the X should be about 2 or 3 mm long. Insert the tip of the nozzle through this cut into the straw. Put the large end of the nozzle into the beaker of water.

B. Put one finger near the end of the straw. Blow hard through the straw at your finger. Watch the water level in the dropper nozzle.



- 6-1. What happened to the water level in the dropper nozzle?

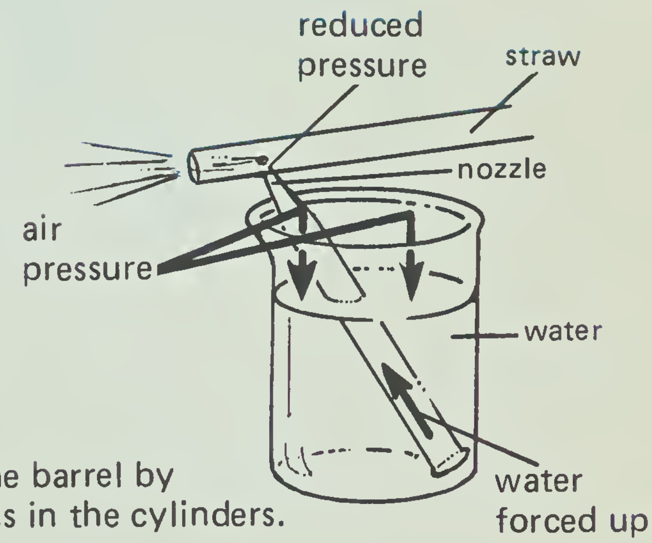
- 6-2. Did any of the water come out of the straw? How could you tell?

- 6-3. Why do you think water came out of the straw?

6-1. It rose all the way.

6-2. Yes; finger got moist.

6-3. The difference in air pressure causes water to rise in the dropper.



The flow of air through the straw reduces the air pressure at the nozzle. So, the greater air pressure on the water surface forces water up into the dropper and out the nozzle.

Gasoline sprays into a carburetor in a similar way. It comes out in small droplets so that it can be vaporized quicker. Figure 6-1 below shows the way gasoline is mixed with air in a carburetor.

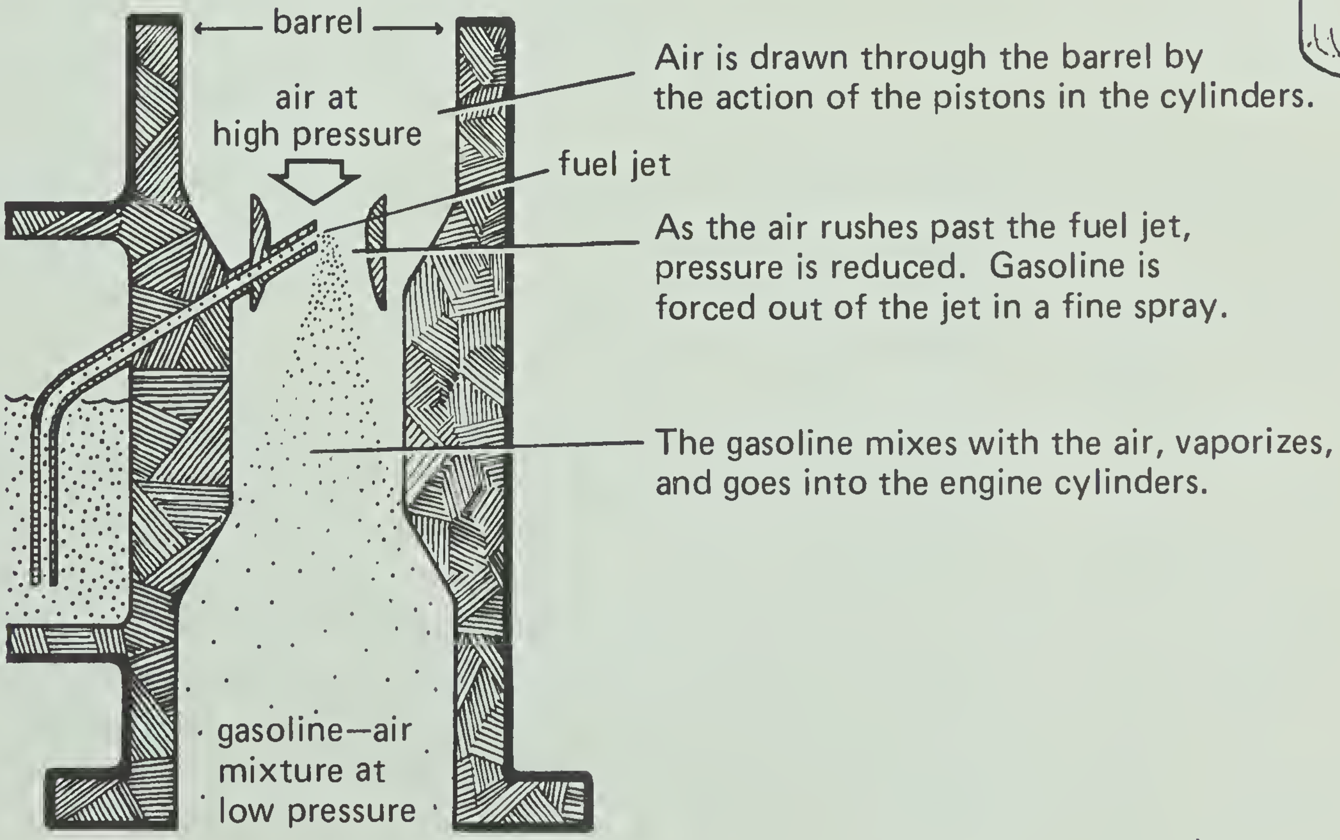


Figure 6-1

Most high school auto shops have a carburetor.

Figure 6-2 below shows the relation of the parts in a simple carburetor. Notice the gasoline inlet, float bowl, float and float valve, and fuel jet and barrel. The two illustrations show how proper fluid level is maintained in the bowl.

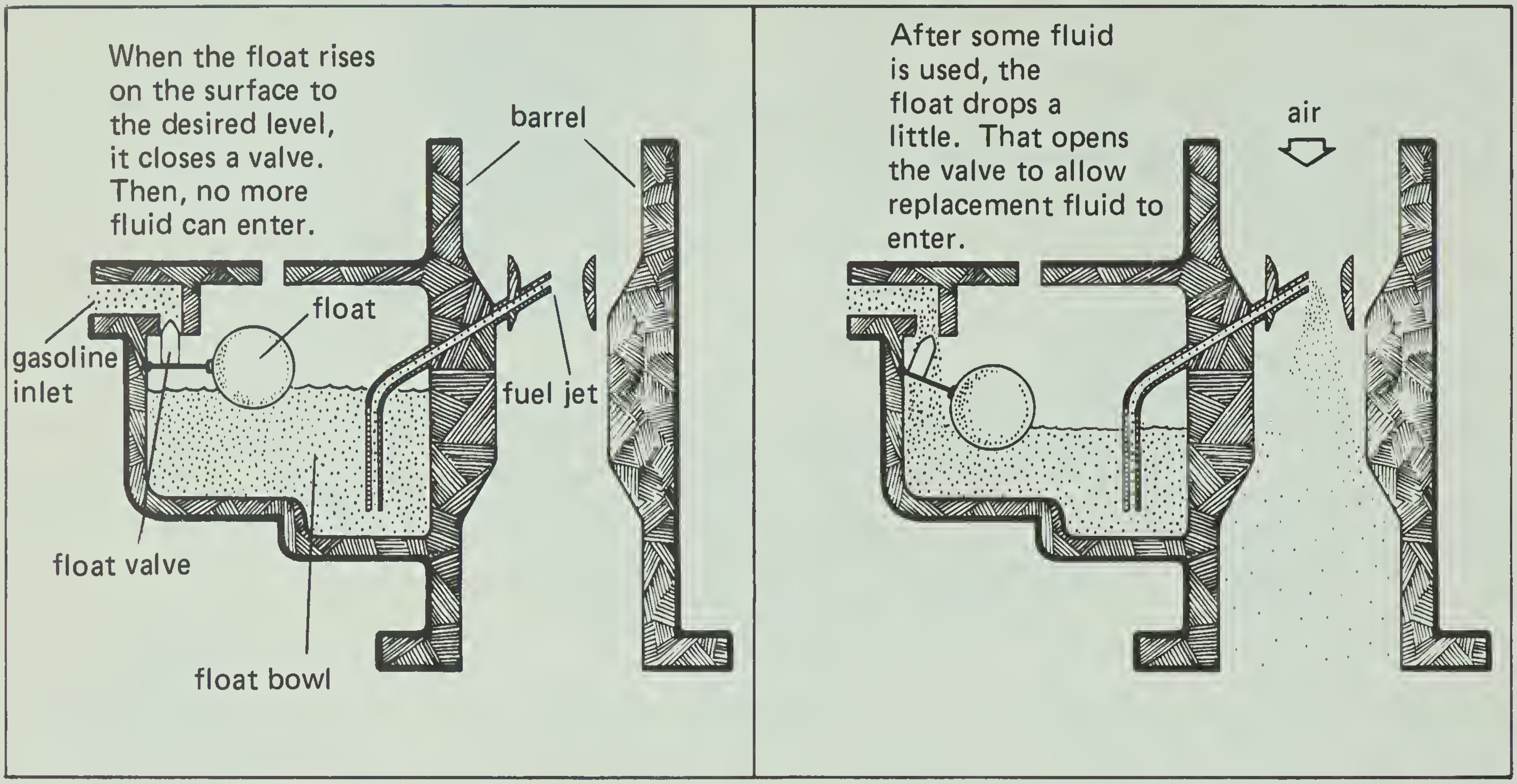


Figure 6-2

For fuel to burn correctly, it must be clean. And the carburetor must be properly adjusted. An air—fuel mixture that's too rich may not even ignite at all. This is called *flooding*. The opposite extreme is a lean mixture with too little fuel in it.

6-4. Too rich

☆ **6-4. Suppose dirt prevents the float valve from closing. Or suppose the float level is set too high. In either case, too much gasoline comes through the jet. Is the carburetor producing a mixture that's too rich or too lean?**

Sometimes the engine needs a richer mixture — especially when the engine is cold and just being started. The enrichment is provided by means of the choke, which reduces air intake.

Most cars have an automatic choke. It's opened and closed by a thermostat. Some cars have a manual choke, and the driver adjusts it with a knob. Either way, the choke plate is positioned between the air intake and the barrel. Figure 6-3 (page 33) shows an automatic choke on a carburetor of a four-cylinder engine.

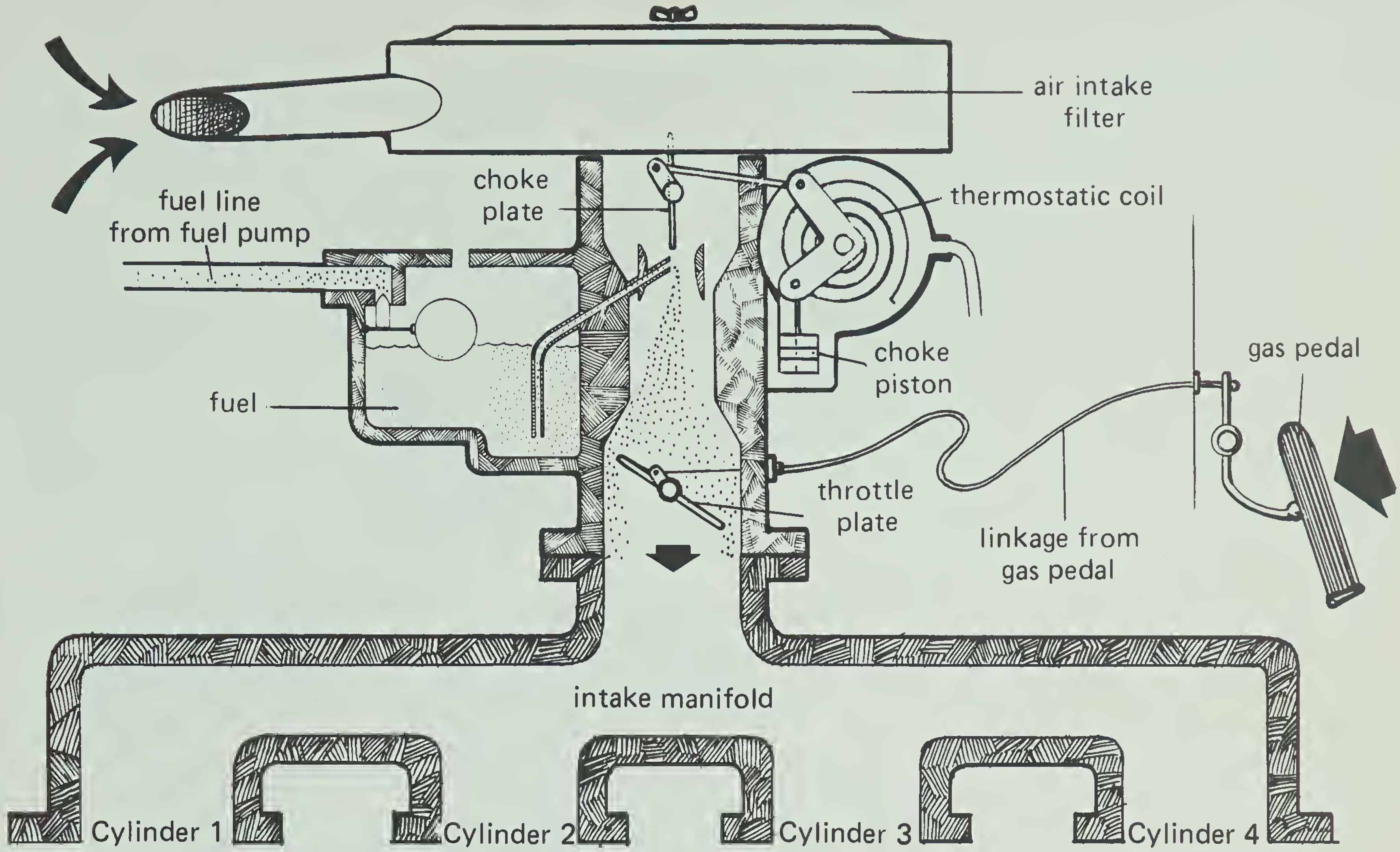


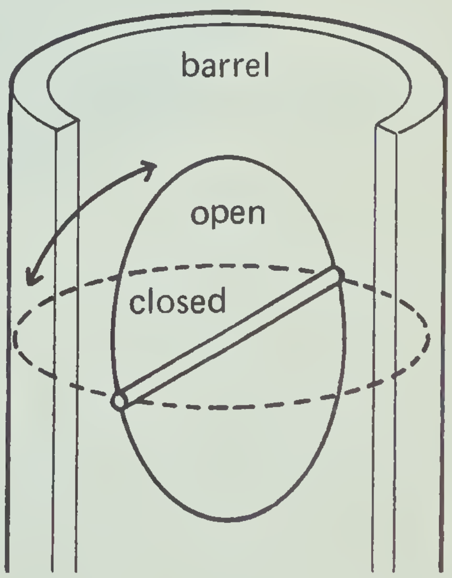
Figure 6-3

- 6-5. Which flow is directly controlled by the choke?

A. Air flow from the air filter
B. Air—fuel mixture flow to the intake manifold
C. Fuel flow to the barrel
D. Fuel flow to the float bowl

6-5. A

This is the way both the throttle plate and the choke plate work.



The choke plate shown in Figure 6-3 above is open. This lets in lots of air and produces a lean air—fuel mixture. Notice that a clogged air filter would act on the engine just like a closed choke plate. It would starve the engine of air, making the fuel mixture too rich.

Look at Figure 6-3 again. Toward the bottom of the barrel, below the fuel nozzle, is the throttle plate. It's a valve that is connected to the gas pedal inside the car. When you step on the gas pedal to get more speed, the throttle plate opens, increasing the air—fuel flow into the cylinders through the intake manifold.

6-6. Fairly slow

6-7. A5, B4, C8, D1, E7, F2, G6, H3

● 6-6. From the adjustment of the carburetor parts, would you say that the engine in Figure 6-3 (page 33) is going fairly fast or fairly slow?

☆ **6-7. Match each fuel system part with its function.**

Part	**Function**
A. Choke plate	**1. holds supply of gasoline**
B. Barrel	**2. provides pressure to move gasoline to carburetor**
C. Float valve	**3. pipes to transport fuel**
D. Fuel tank	**4. place where air and fuel are mixed**
E. Intake manifold	**5. regulates air intake to carburetor**
F. Fuel pump	**6. regulates flow of air—fuel mixture from carburetor**
G. Throttle plate	**7. connects carburetor to cylinders**
H. Fuel lines	**8. regulates flow of gasoline from fuel pump to carburetor**

For a brief review, look at Figure 6-4 below. It shows the main components of the fuel system.

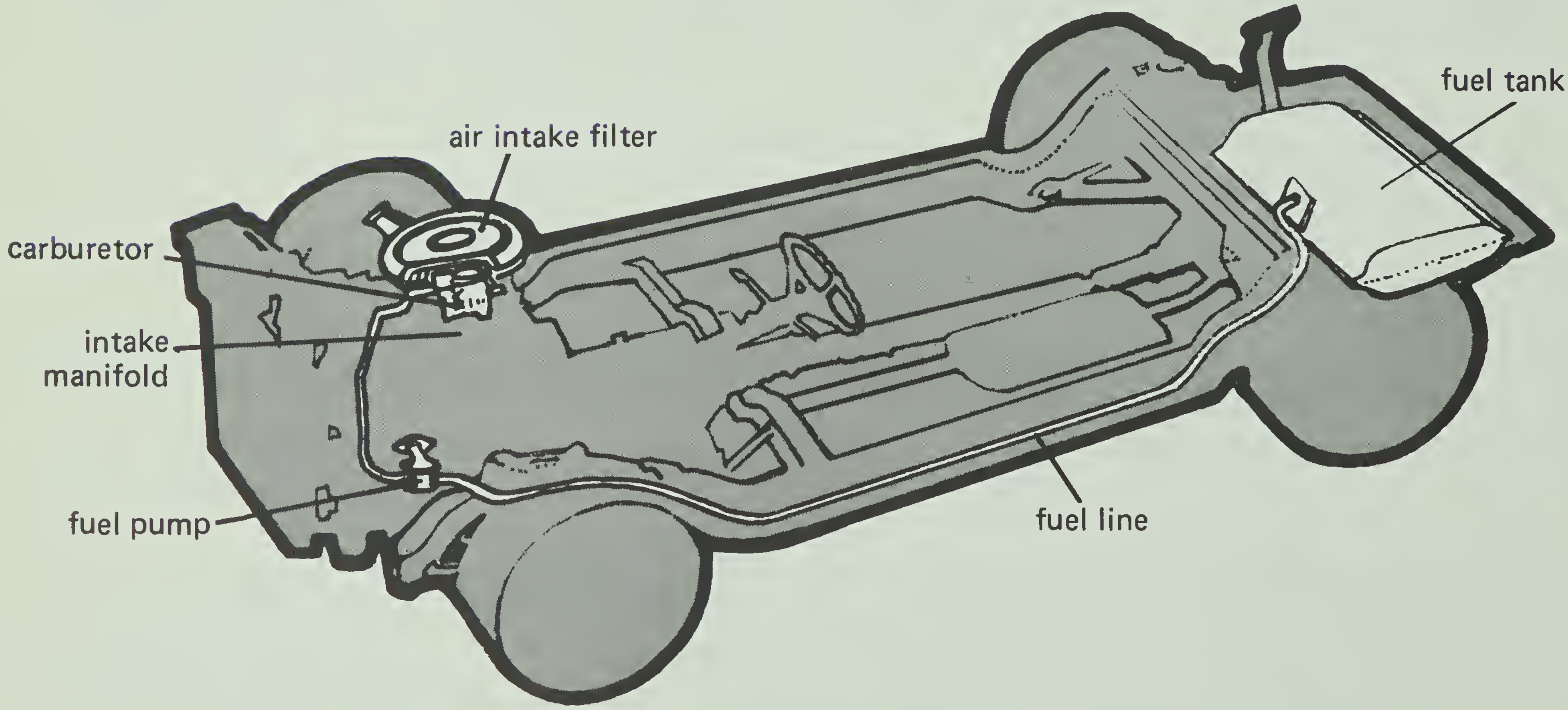


Figure 6-4

☆6-8. Which of the following problems would keep the carburetor from doing its job properly? Check Figure 6-4 (page 34) to identify the parts.

A. Fouled spark plug
B. Clogged air filter
C. Failing fuel pump
D. Blocked fuel line

6-8. B, C, D

The carburetor described in this activity has been used for many years. However, recent advances in electronics have led to another air—fuel mixing system. This new system uses fuel injectors like the one shown in Figure 6-5 below.

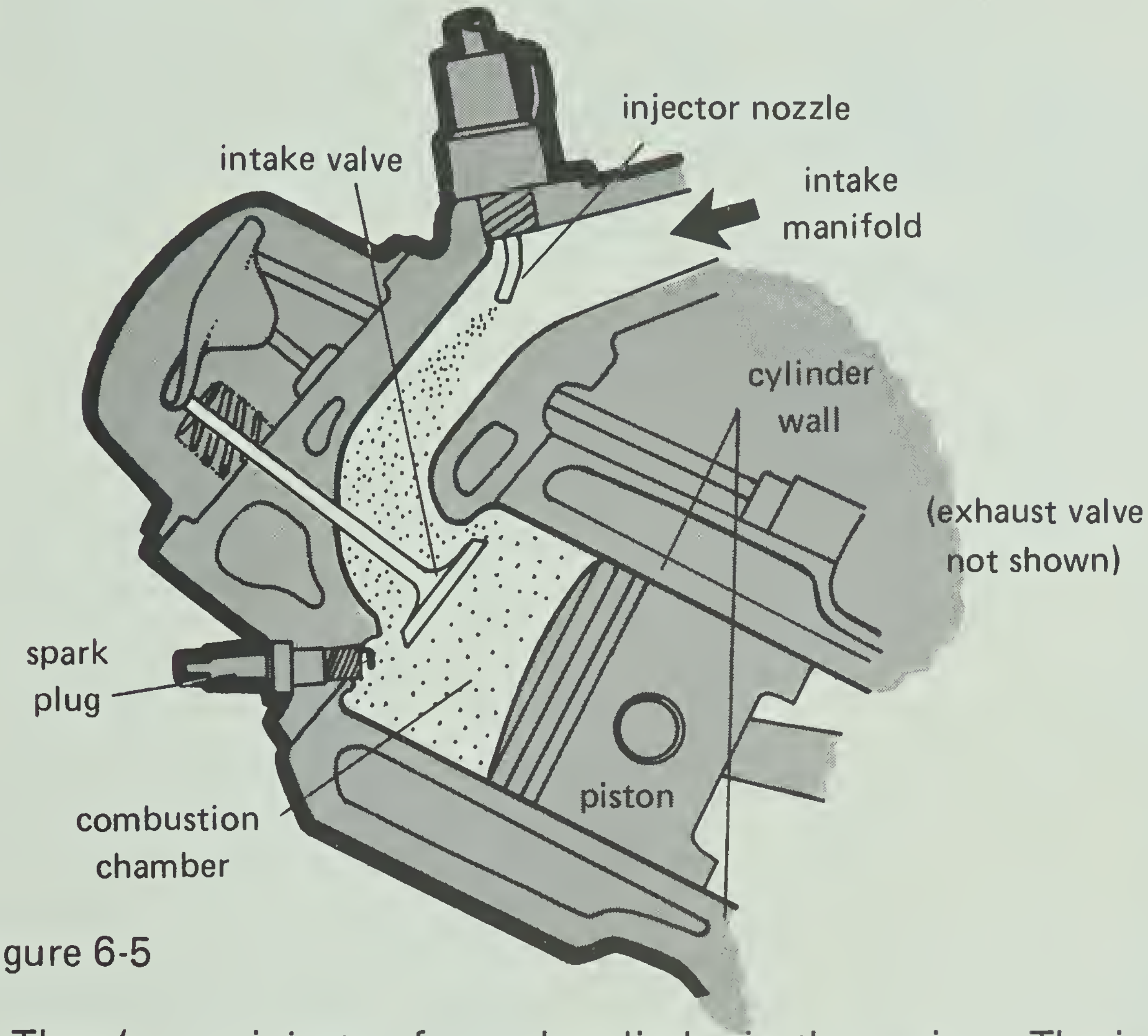


Figure 6-5

There's one injector for each cylinder in the engine. The injectors themselves are nozzles that spray fuel into the air in the intake manifold very near the cylinder's intake valve.

The amount of fuel injected is electronically determined. Several sensors supply information about intake air temperature, engine temperature, manifold pressure, engine load, and accelerator pedal pressure from the driver's foot. An electronic computer then decides on the proper fuel mixture. It acts by controlling the length of time that the injector valve is open. The fuel burns much more completely in a fuel-injected engine than in a carbureted engine. This reduces pollution and saves fuel.

ACTIVITY EMPHASIS: Lubricants decrease friction between parts that are in contact. Lubricants also remove harmful materials, transfer heat, and protect against corrosion. To protect the engine, car owners should change engine oil according to the manufacturer's recommendations. Oil of the proper grade (viscosity) and amount should always be used.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

ACTIVITY 7: OILING

Whenever objects rub together, there will be friction. The book and tabletop shown in Figure 7-1 below push against each other. The downward force of the book is equaled by the upward force of the tabletop. And as the boy pushes the book across the table, the table pushes back. This horizontal push by the table is the friction force it exerts on the moving book. One of the main functions of a lubricating oil is to reduce friction.

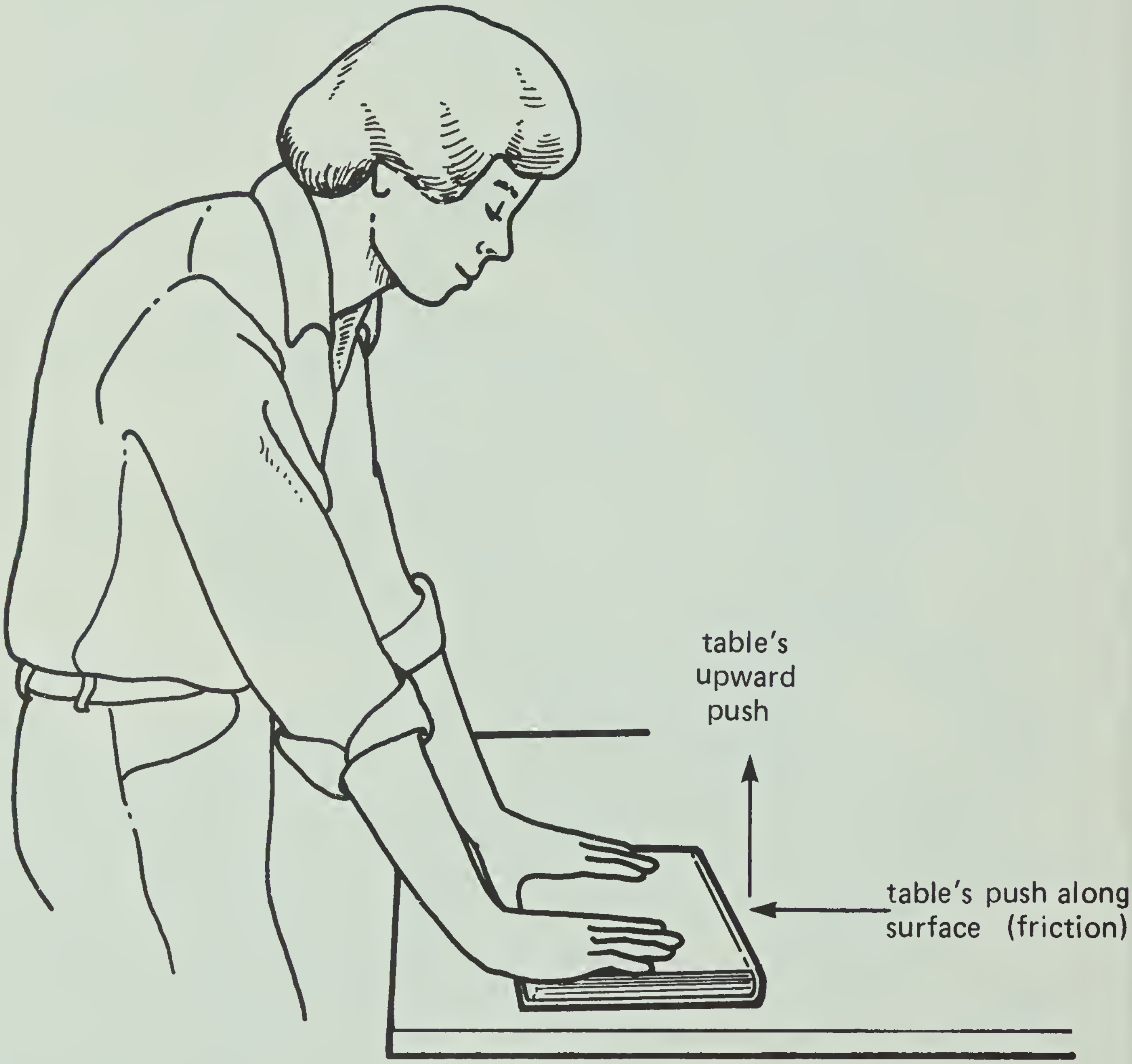


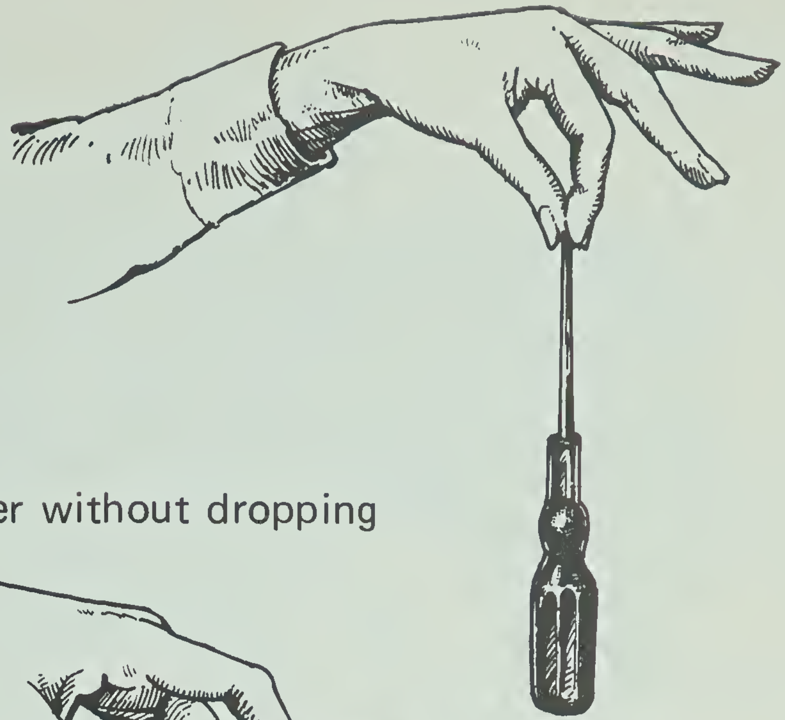
Figure 7-1

You can see for yourself how lubricating oil reduces friction between surfaces in contact. You'll need the following materials.

Since screwdrivers vary widely in weight and smoothness, it is a good idea to try this investigation before your students do it.

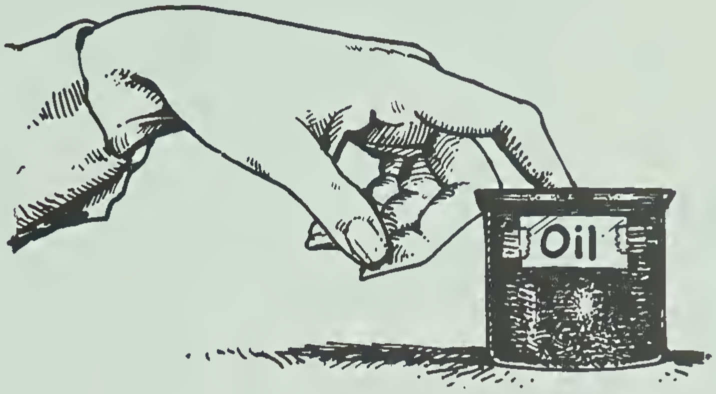
screwdriver
container of oil
paper towels

A. Thoroughly clean and dry the blade of the screwdriver. Then grasp the tip of the blade tightly between your thumb and forefinger, letting the screwdriver hang down freely.



● 7-1. Were you able to hold the screwdriver without dropping it?

B. Dip the tip of your forefinger into the container of oil. Touch it to your thumb so that both your thumb and forefinger have oil on them.



C. Hold the screwdriver by the handle with the blade upward, using the hand without oil. Grasp the tip of the blade tightly between your oily thumb and forefinger. Release the screwdriver from your other hand, but keep that hand ready to catch it if it falls.

● 7-2. Explain what happened this time.

☆ **7-3. What does the oil do to the friction between your thumb and finger and the screwdriver?**

D. Wipe the oil from your fingers and from the screwdriver blade. Then wash your hands with soap and water.

7-1. Yes

7-2. The screwdriver slipped out of the fingers.

7-3. The oil reduced the friction.

In a modern car engine, the oil circulates under pressure. The oil has several important jobs, as shown in Figure 7-2 below.

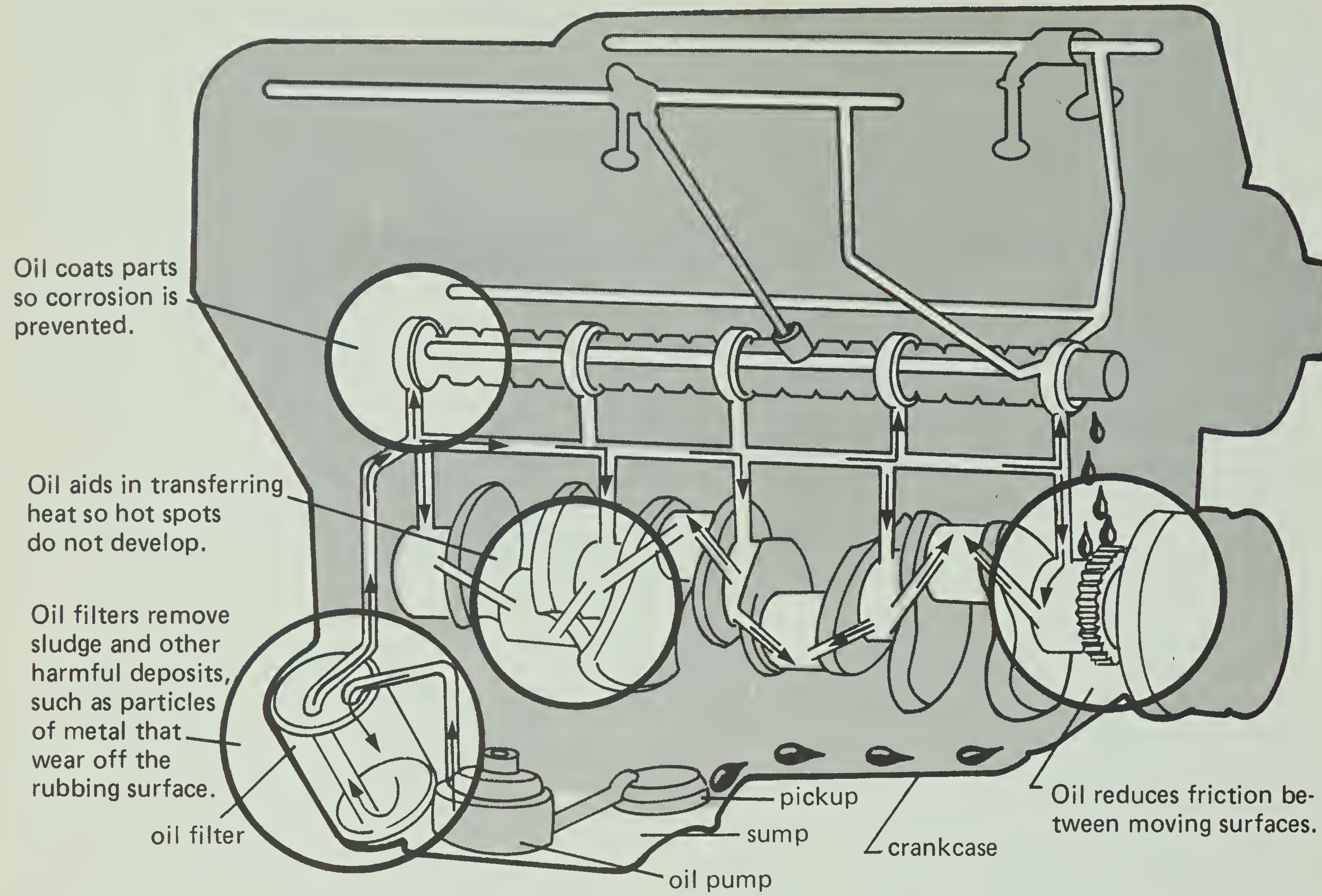


Figure 7-2

Because the oil picks up particles of dirt and metal, it needs to pass through an oil filter that will screen them out. This filter is usually changed whenever the oil is changed.

You may be wondering why the oil needs to be changed at all if the oil filter does a good job. One problem is that not all the impurities that get into the oil can be filtered out.

One impurity is water. As gasoline burns, water vapor is produced. Most of this water vapor goes out the exhaust along with other gases of combustion. But some of it gets into the oil and is carried to the crankcase.

When the engine is running, the crankcase vapors are ventilated and removed. But when the engine is shut off, some water condenses in the sump (bottom of the crankcase). Then, when the engine is restarted, the water gets mixed with the oil. This mixture combines with other waste products to form corrosive acids, gums, varnish, and sludge. Look at Figure 7-3 (page 39).

A gasoline engine may produce as much water by volume as it burns gasoline.

Late model cars have Positive Crankcase Ventilation (PCV), which recycles crankcase vapors to the intake manifold.

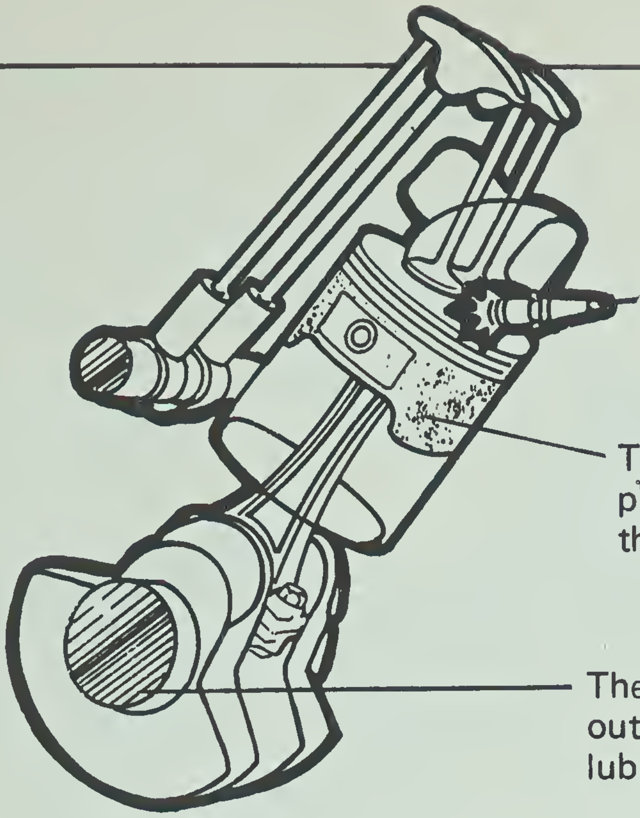


Figure 7-3

Oil contamination is not just a problem of the number of miles a car is driven. If a car is driven often for short distances, its engine gets started and stopped a lot. The engine oil may collect water and other contaminants quicker than the oil in a car driven long distances.

Finally, engine oil normally contains a number of additives. These help the oil do its many jobs. But the additives gradually burn away in time.

☆ **7-4. Why should engine oil be changed periodically rather than just kept at the proper level?**

7-4. Oil gets dirty. It acquires contaminants, such as acids and gums. It eventually loses its additives.

● 7-5. Why do most car manufacturers recommend changing engine oil after a certain period of time regardless of mileage?

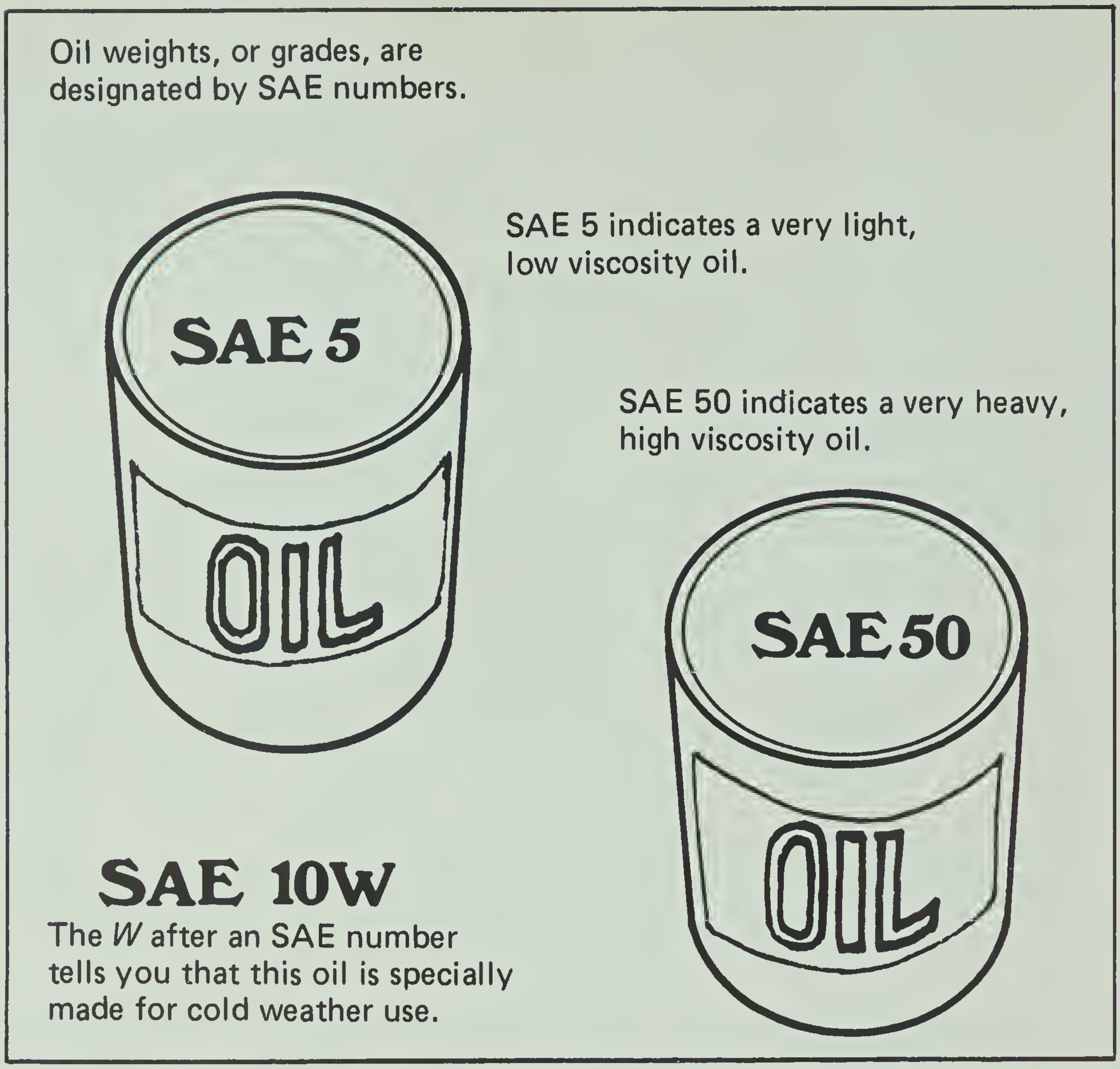
7-5. Oil is contaminated every time the engine is allowed to cool. Moisture buildup produces damaging acids.

Different fluids flow at different rates. For example, water is easier to pour than syrup at the same temperature. The measure of a fluid's resistance to flow is its viscosity [vis-KOSS-i-ty]. Thus, syrup is more viscous than water.

As an oil heats up, its viscosity goes down. It flows more easily. Cold oil is more viscous. After an engine has been sitting for a while, its oil has cooled. Moreover, most of the oil has drained into the sump. Many engine surfaces, especially the up-and-down ones such as cylinder walls, will be nearly dry of oil.

If the cold oil is highly viscous, it won't get to the dry parts fast enough when the engine starts up. The parts could be damaged. On the other hand, if the cold oil has very low viscosity, it may thin out too much as it heats up. Very thin oil can't properly coat engine parts. An engine running fast at high speeds is not well protected by low viscosity oil.

The Society of Automotive Engineers (SAE) has set standards for oil viscosity.



A new engine driven at low speeds in cold weather should probably use a light grade of oil – SAE 10 or 10W. The same engine in summer might be better off with SAE 30, 40, or 50.

As an engine gets older, its parts wear down. And the spaces between parts get larger. Then even the more viscous oils can be pumped to the moving parts quickly.

For older cars, there's an advantage to using heavier grades of oil. The thicker, more viscous oils have less tendency to seep past worn piston rings into the combustion chambers of the cylinders. So a worn engine burns less oil if the oil is thick.

7-6. SAE 30

• 7-6. Suppose you're buying oil for a car that has gone 80,000 miles. Which grade of oil would normally be best – SAE 10W, SAE 20, or SAE 30?

Some car manufacturers may recommend multigrade oils with designations such as *5W20, 10W40,* and *10W50*. These are all-weather oils. They are blends of different viscosities. They protect an engine in all conditions from cold starts to highway driving.

The engine isn't the only part of a car that needs lubrication. Some lubricant is called for wherever two moving surfaces are in contact. That includes transmission, differential, joints in the steering linkage and suspension, and even door locks and hinges. The entire car should be lubricated regularly. Look at Figure 7-4 below. Several different kinds of lubrication are needed for these parts.

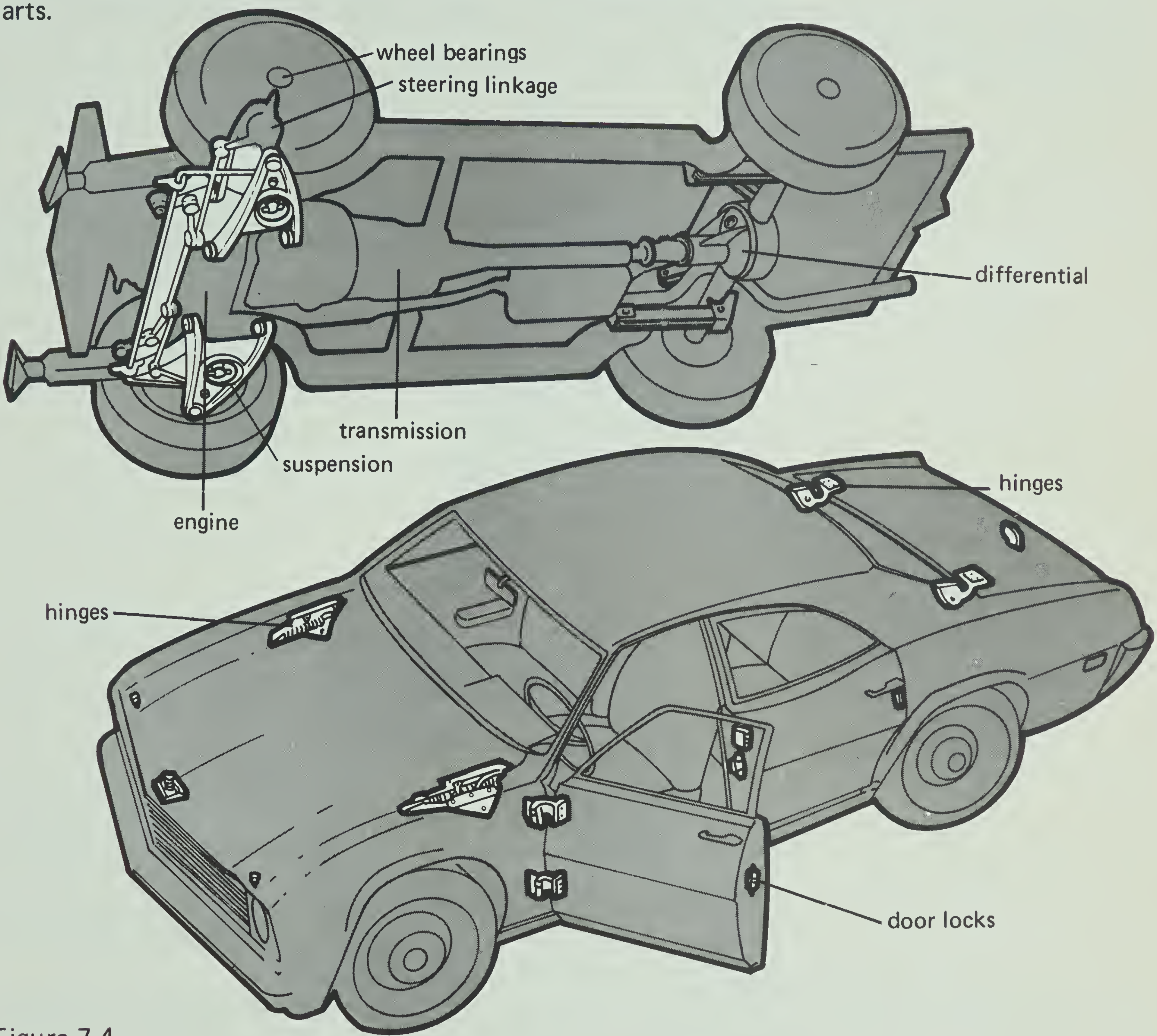


Figure 7-4

● 7-7. How many different places (labeled or shown heavy) call for lubrication in Figure 7-4 above?

7-7. At least eighteen

It's best to follow the exact lubrication recommendations for a particular car. They can be found in the owner's manual.

ACTIVITY EMPHASIS: Pressure is force per unit of area, as illustrated by the contact of tire surface with the road. Tires that are underinflated or overinflated have contact characteristics that lead to uneven wear.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

ACTIVITY 8: GETTING A GRIP ON THINGS

Which is more tiring — standing flat on your feet or standing on tiptoes? The answer — on tiptoes — is obvious, but the reason may not be. It's at least partly a matter of pressure. All your weight is pressing down on the small contact area between your toes and the floor. Pressure equals force (weight) per unit of area.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{or} \quad P = \frac{F}{A}$$

Your toes have much less area than your flat feet. Therefore, the pressure on your toes is much greater when you're on tiptoes. This higher pressure is transmitted to the supporting muscles in your feet and legs, and you get tired more quickly.

8-1. Force per unit of area ($P = F/A$)

● 8-1. What is pressure?

If you had trouble answering Question 8-1 above, read "Resource Unit 6: Pressure." Don't go on until you understand what pressure is and how it's described.

Let's see how the units for measuring pressure work out. If pressure is force per unit of area, you have to know how force and area are measured to get the pressure.

Force is a push or a pull. The force of weight of an object, for example, is the downward pull due to gravity. Force is measured in *newtons* (N). Area is measured in *square metres* (m^2). Pressure is thus newtons of force divided by square metres of area (N/m^2). A newton per square metre is called a *pascal* (Pa).

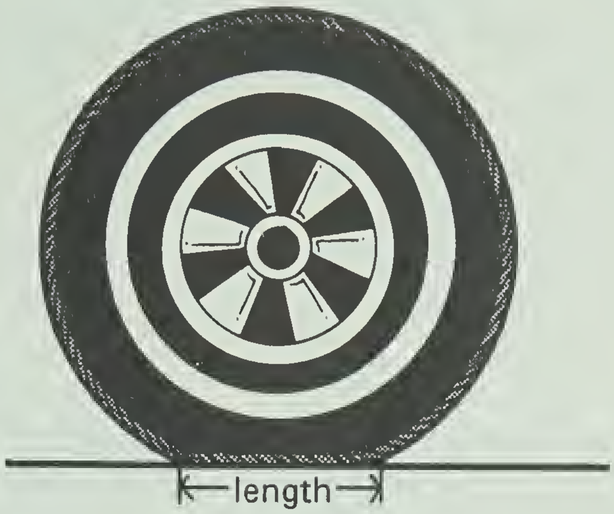
8-2. Pascals (pa)

● 8-2. What is pressure in N/m^2 called?

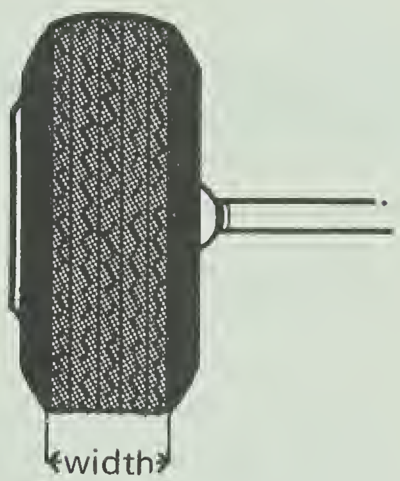
A newton is a small force to be spread over such a big area as a square metre, so a pascal is a small unit. Ordinary air pressure is often given in kilopascals, which is pascals divided by 1000. For example, a pressure of 30 lbs per square inch in a tire is 207,000 pascals, so it is convenient to give it as 207 kPa.

Automobile tires are subjected to pressure too. A car's full weight is supported by the contact area between the road and the four tires. You can calculate this pressure. First, you need to measure the area of contact. You'll need a metric ruler. If you're not sure how to use the metric ruler, read "Resource Unit 9: Measuring Length." Then do Step A.

A. Go to the parking lot. Pick out a medium-sized car. Measure the length in centimetres of the road contact along the side of the tire. Record the length in your notebook.



B. Measure the width in centimetres of the road and tire contact. Record this number. Return to your classroom.



C. Change the centimetres you measured in Steps A and B to metres by dividing each figure by 100. Then calculate the area of contact by multiplying length times width.

● 8-3. What is the area of contact in square metres (m^2) from Step C?

8-3. [Answers will vary, but will probably be about 0.022 m^2.]

Suppose you measured 22 cm in Step A and 10 cm in Step B. These would change to 0.22 m and 0.10 m in Step C. Then, multiplied together, they would equal 0.022 m^2. Your answer in Question 8-3 might be larger or smaller than 0.022 m^2, depending on your measurements.

Now suppose the car weighs 15,000 newtons. Each tire must support one-quarter of this weight, or 3750 N. If you divide this downward force by the area you found in Step C, you get the pressure on each tire in pascals.

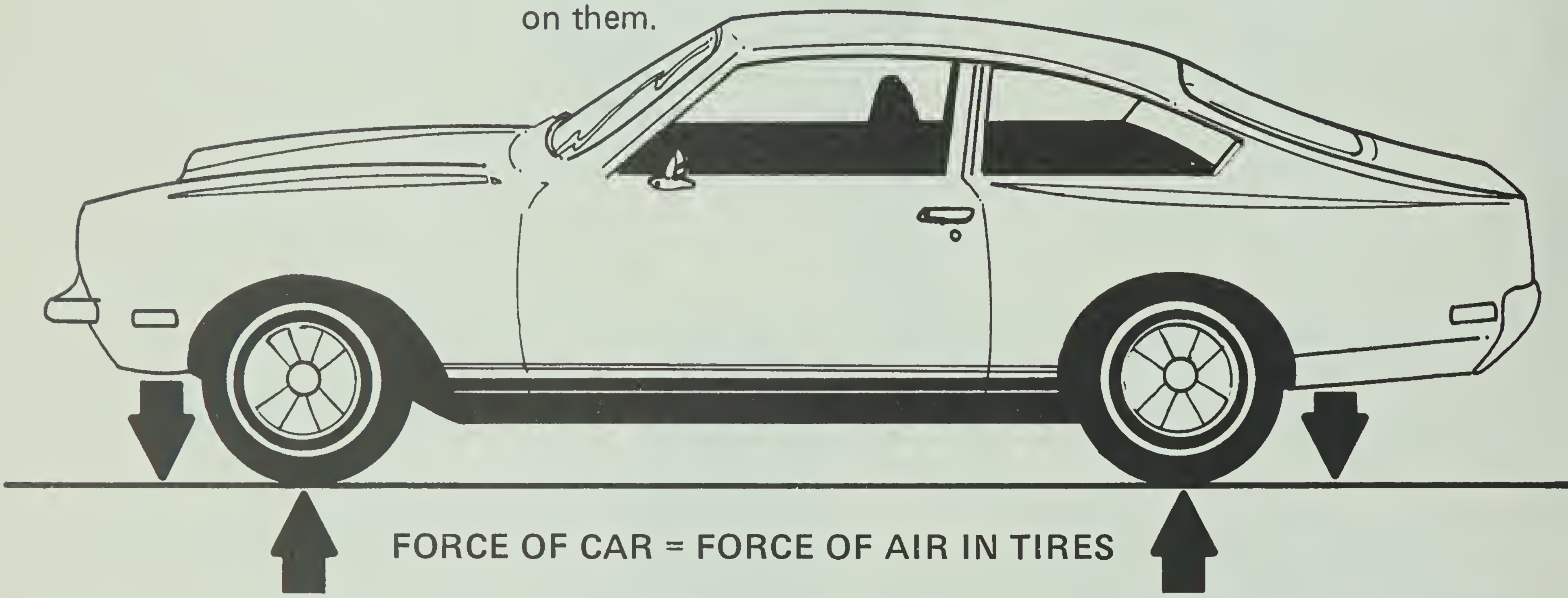
$$\frac{15{,}000\ \text{N}}{4} = 3750\ \text{N on each tire}$$

$$\frac{3750\ \text{N}}{0.022\ \text{m}^2} = 170{,}455\ \text{pascals}$$

Dividing by 1000 changes the pascals to kilopascals.

$$\frac{170{,}455}{1000} = 170.5\ \text{kPa}$$

The tires must then be inflated to support this much force. The pressure inside the tires has to equal the pressure of the car on them.



FORCE OF CAR = FORCE OF AIR IN TIRES

8-4. It goes up. [P = F/A. Since F is constant, P varies inversely with A.]

● 8-4. Notice what happens when a tire starts to go flat. As the pressure goes down, what happens to the tire's area of contact with the road?

The force remains the same. So if pressure is decreased, the area of contact must increase. And, if pressure is increased, the area of contact must decrease.

Tires must also withstand impacts while the car is being driven at speeds up to 90 km/h on all kinds of road surfaces. Today's tires have been designed to perform well under this strain. But they must be properly inflated. If they aren't, they'll wear out faster than they should.

After many thousands of miles of driving, properly maintained tires will show an even wear across the width of the tread. Underinflated tires wear on the edges. Overinflated tires wear in the middle. Figure 8-1 below shows this.

A local garage may have real samples of these. Or you may wish to sponsor a parking-lot survey.

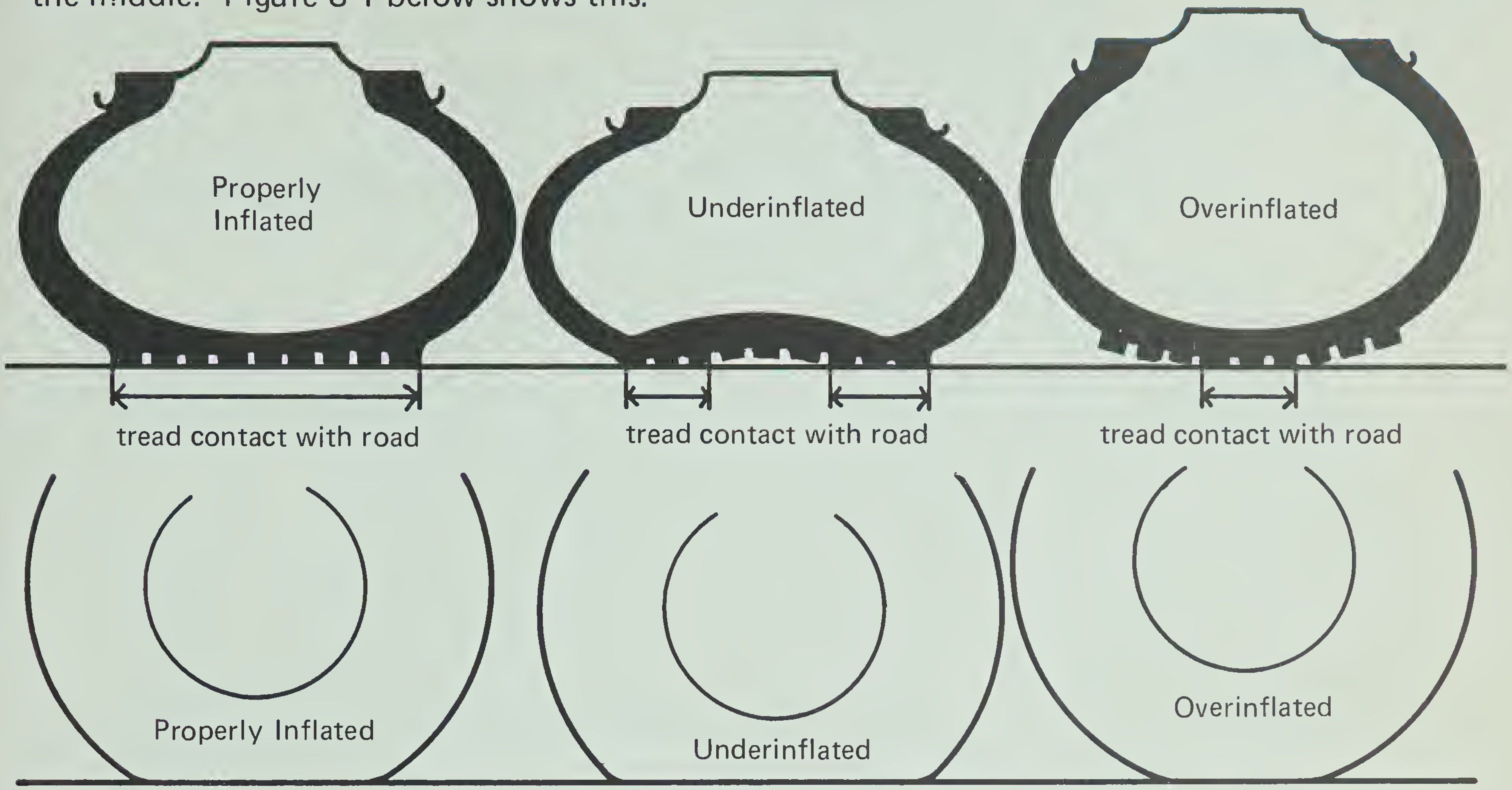


Figure 8-1

☆ **8-5. Which tire in Figure 8-1 above will last the longest and be safest to drive?**

8-5. The properly inflated tire

By checking your own tires for tread depth, you can tell whether they are safe or not. The easiest way is to look for the tread-wear indicators built into the tire. Figure 8-2 shows what they look like when the tread is worn down. This indicates that the tire should be replaced.

☆ **8-6. Which has more tread surfaces to grip the road — a new tire or a worn tire?**

8-6. A new tire

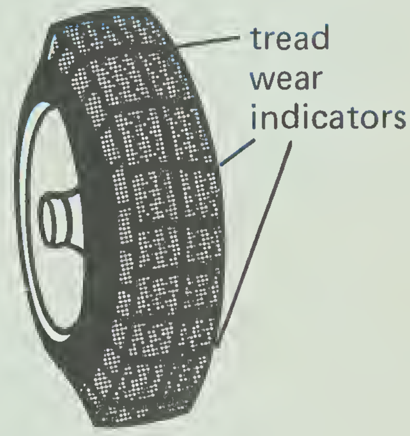
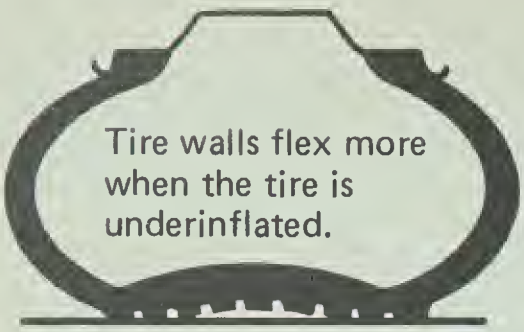


Figure 8-2

When tires are able to grip the road, they are said to have *traction*. Traction refers to the friction between the road and the tires that allows stopping and acceleration. When roads are icy, muddy, or wet, traction is reduced. Tires with worn treads can become dangerously slick.

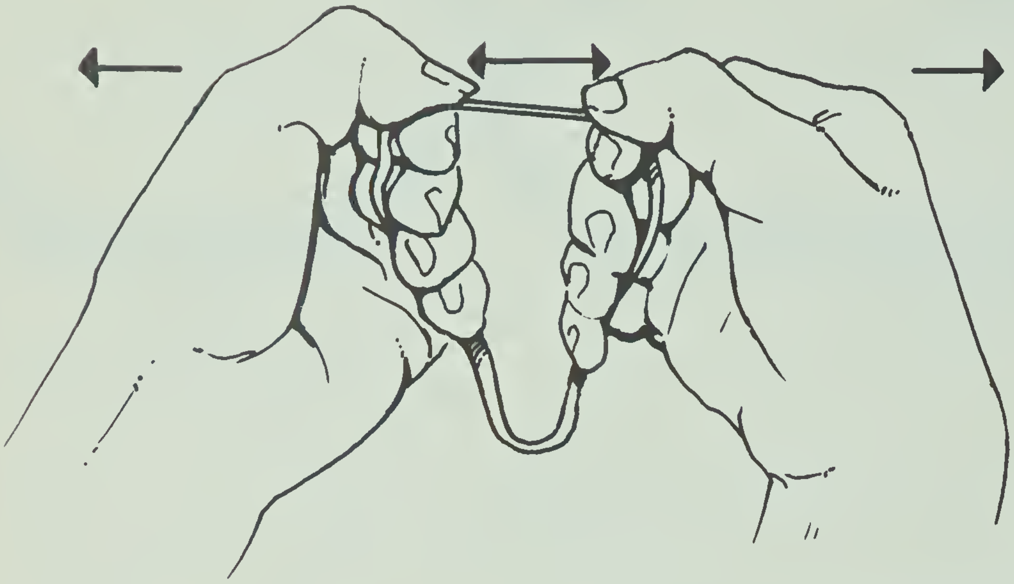
In emergencies, it is possible to increase traction somewhat by letting some air out of the tires. This increases the area of contact.

Although friction does not necessarily get greater as the area of contact between uniform surfaces gets bigger, the road surface is seldom very uniform. Thus, an increased area gives a better chance of contact with some less slick spots.



Lots of people drive on underinflated tires because lower pressure cushions bumps and gives a more comfortable ride. But lower tire pressure has drawbacks too. When a tire is driven at a lower pressure than it was designed for, the tire walls flex more than they should.

To see how this overflexing affects a tire, get a rubber band.



A. Hold the rubber band as shown. Flex (stretch) the top part very fast for about a minute.

B. Touch the stretched part to your cheek. Then touch the unstretched bottom part to your cheek.

8-7. The one you flexed

● 8-7. Which part was warmer?

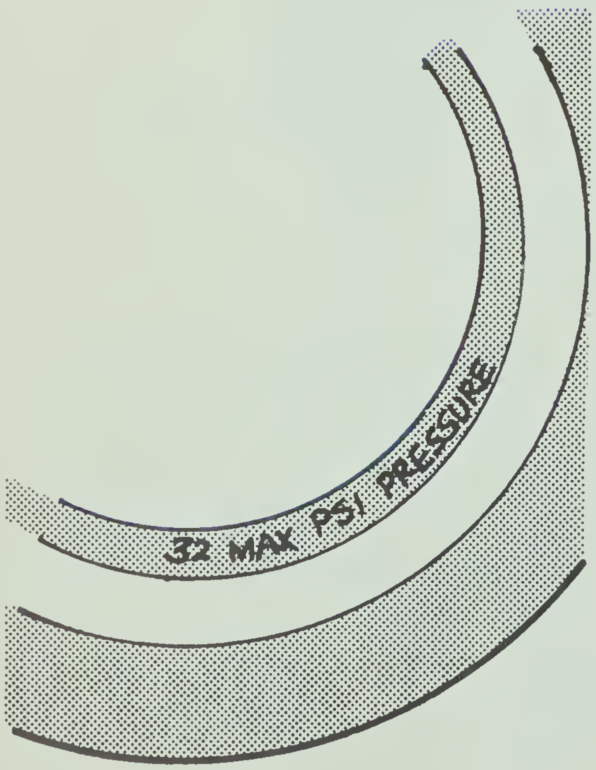
Excessive flexing causes heat buildup. This shortens tire life. The heat strains and weakens the sidewall material. Tire flexing also hurts gasoline mileage and thus wastes fuel. When test drivers set gasoline mileage records, they overinflate their tires for less road friction and better fuel economy.

8-8. Less; less; more

☆ **8-8. Does increasing tire pressure give a more or a less comfortable ride? More or less traction? More or less fuel economy?**

8-9. More; more; less

☆ **8-9. Does reducing tire pressure give a more or a less comfortable ride? More or less traction? More or less fuel economy?**



The maximum safe air pressure is printed on the sidewall of each tire sold in the United States. If the pressure exceeds this limit, there is danger of damage to the tire. The chance of a blowout, however, is also great when the tire is underinflated.

Check tire pressure when the tires are cold. That's the condition the recommended pressures refer to. Tires heat up from driving, and the air pressure increases. But don't let any air out. The pressure will go back down when the tires cool. If the car has been driven more than a kilometre or two, let it sit for about three hours to ensure an accurate, cold, tire reading. A tire hot from the road may be twenty percent or more above its cold pressure.

ADVANCED

ACTIVITY 9: PLANNING

Activity 10 — Page 49

Objective 10-1: Tell what elasticity is and how it is used in car suspension systems.

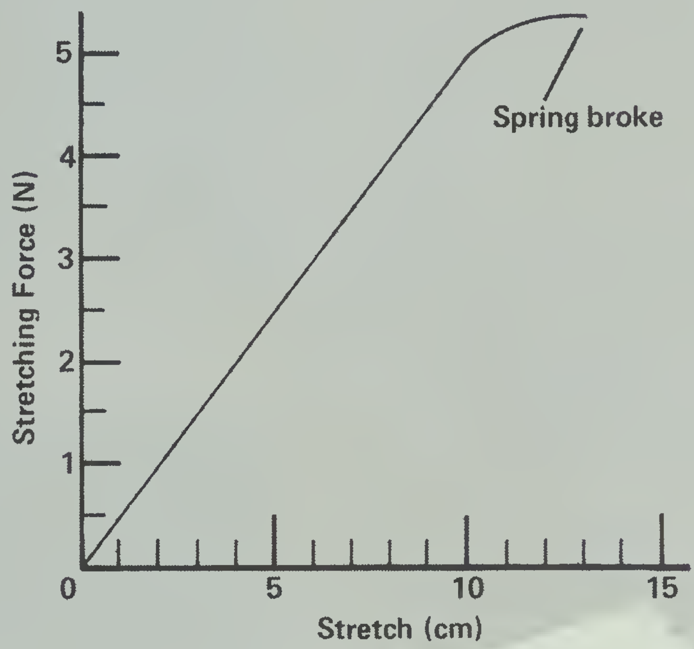
Sample Question: How are the elastic properties of springs in a car used to smooth out a rough ride?

A. The springs stretch the same amount for any force and therefore allow the car body to remain stable.
B. The springs allow the wheels to move up and down without jolting the car body.
C. The springs keep the car from moving up and down at all.
D. The springs allow the car to move up and down, but they keep the wheels from bouncing.

Objective 10-2: Using a graph, interpret the relationship between elongation and applied force, as shown by Hooke's law.

Sample Question: Look at the graph below. It shows that the spring obeyed Hooke's law within the range of elongations from

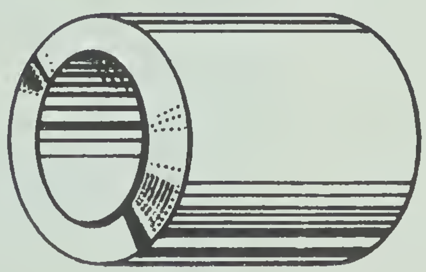
A. 0 to 10 cm.
B. 10 to 15 cm.
C. 0 to 15 cm.
D. left to right.



Activity 11 — Page 53

Objective 11-1: Describe how temperature affects the expansion and contraction of metal parts in a car engine.

Sample Question: Look at the car cylinder shown at the right. Suppose it was heated. Would the center space get larger or smaller?



Answers: 10-1. B; **10-2.** A; **11-1.** larger

Activity 12 Page 56

<u>Objective 12-1:</u> Describe how friction forces are responsible for starting, stopping, and turning a car, and explain how static friction differs from kinetic friction.

<u>Sample Question:</u> What makes static friction different from kinetic friction?

A. Only static friction involves motion.
B. Only static friction develops heat.
C. Only kinetic friction involves relative movement between two bodies.
D. Kinetic friction is always bad, but static friction isn't.

Activity 13 Page 62

<u>Objective 13-1:</u> Use the kinetic molecular theory to explain how work is done during a piston's power stroke and why the temperature of air increases during a compression stroke.

<u>Sample Question:</u> When a gas is compressed, its temperature increases. According to the kinetic molecular theory, why does that happen?

A. As the gas is compressed, the molecules get farther apart.
B. The average kinetic energy of the molecules increases when the compressing surroundings do some work on the gas.
C. The average kinetic energy of the molecules increases when the compressing gas does some work on its surroundings.
D. Compressing the gas keeps the molecules from moving.

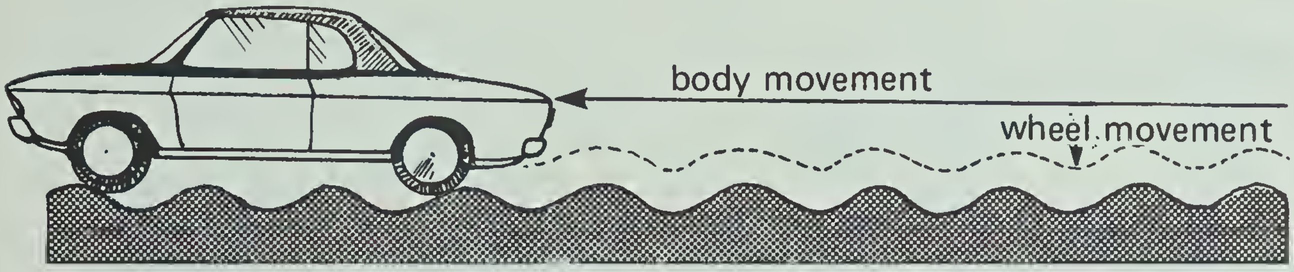
Answers: 12-1. C; **13-1.** B

ACTIVITY 10: SMOOTH RIDING

ACTIVITY EMPHASIS: Within a spring's elastic limit, the amount of its stretch is proportional to the force applied. Shock absorbers are used to damp the oscillations of the car's suspension system.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

If you ever rode in a wagon, you may remember how every rough spot in the road jolted you. The reason is that wagon wheels are on axles that are rigidly fastened to the frame. The wheels of a car, on the other hand, are connected to the frame through a suspension system. This system cushions shocks. It lets the car body travel forward with little up-and-down motion. And it lets the car take turns with less tendency to skid or roll.



Suspension systems use springs. The materials in the springs have the property of elasticity. An elastic material tends to regain its shape after being deformed.

The law used in designing springs was discovered about three hundred years ago by an English physicist named Robert Hooke. You can rediscover Hooke's law for yourself. You'll need the following equipment.

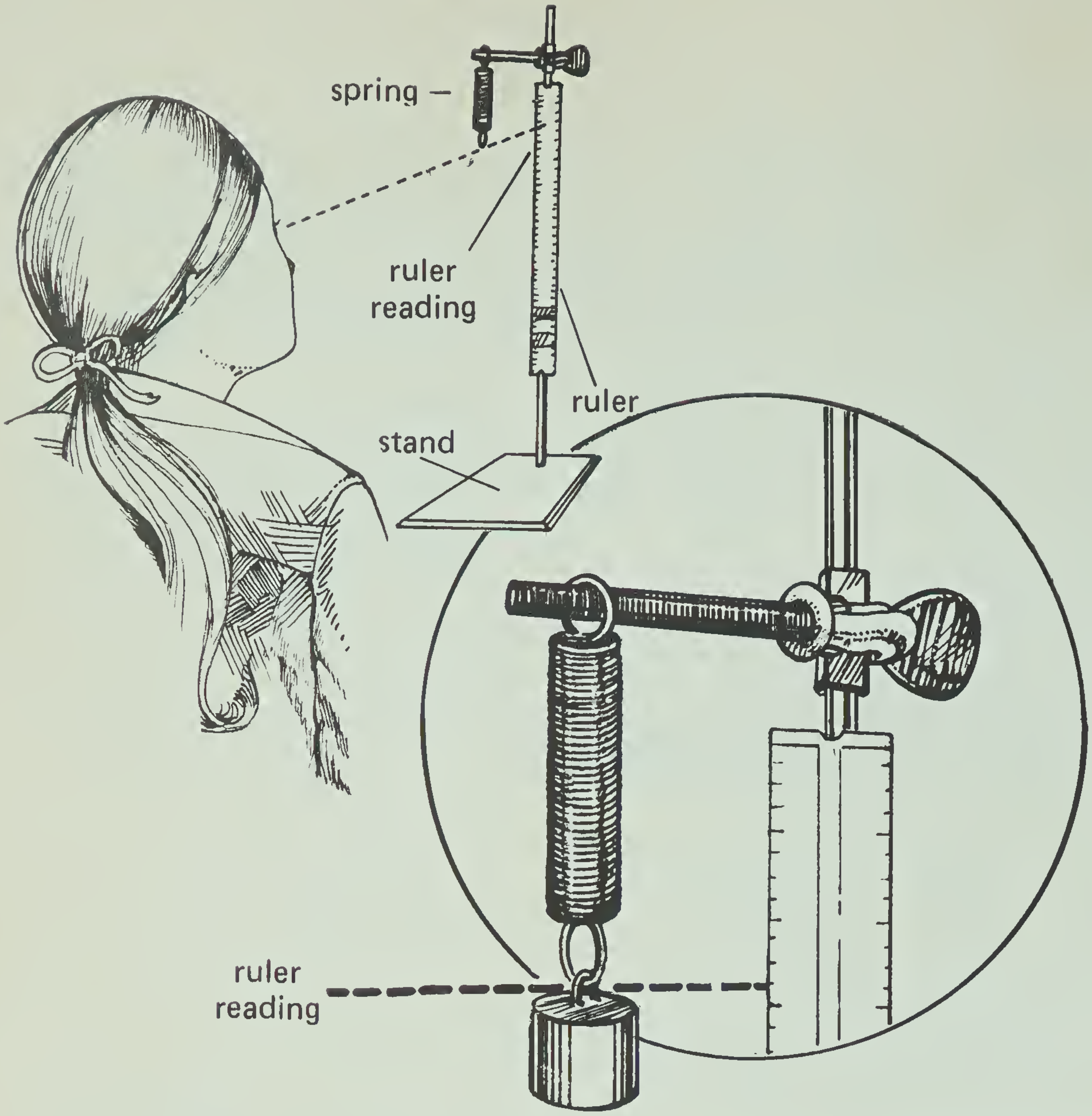
- spring
- stand for suspending spring, with clamp
- several small weights of uniform size
- metric ruler
- plastic or masking tape

If you use 100 g masses, each one will exert a downward force (weight) of about 1 N.

CAUTION	Treat the spring with care. Don't stretch it too far. Use only the loads indicated. Otherwise you might permanently damage it.

A. In your notebook, make a table similar to this. Notice that the "Force" column is in newtons (N), which is the metric unit of force.

NUMBER OF WEIGHTS	RULER READING (cm)	FORCE (N)	STRETCH (cm)
0		0	0
1			
2			
3			
4			
5			
6			



B. Tape the ruler in place near the lower end of the spring. Choose some easily recognizable point on the lower end of the spring. Sight along it to the ruler. Record in the table opposite "0" the ruler reading to the nearest tenth of a centimetre.

C. Attach one of the weights to the bottom of the spring. Now repeat your sighting. Record in your table the new reading on the ruler. Do this six times, each time attaching another weight. Then remove all the weights.

• 10-1. Did the unweighted spring return to its original point?

10-1. Yes

D. Calculate the stretching force and the stretch of the spring for each of your weights and each ruler reading. The stretch is the total amount that the spring stretches. Enter the numbers in the table.

10-2. [Answers will vary.]

• 10-2. Look at the numbers in your table. About how many centimetres of stretch does each additional weight give the spring?

Experimental results such as these are usually plotted on a graph. Even before doing that, however, you can always tell when the smooth curve through your data points will be a straight line. That will happen whenever a fixed change in one of the quantities always corresponds to a fixed change in the other. You changed the downward force on the spring by a fixed amount each time.

10-3. Yes

• 10-3. Did the stretch of the spring increase by about the same amount every time?

E. Make a graph for your own data.

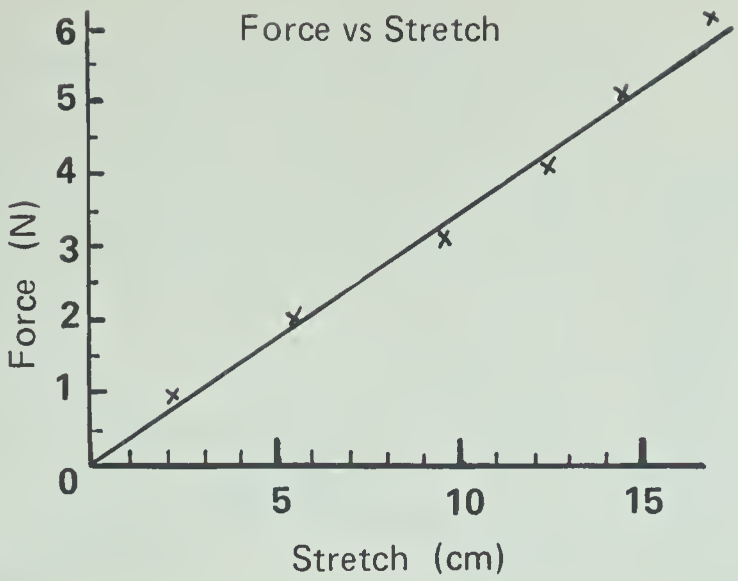


Figure 10-1

A sample graph is shown in Figure 10-1 above. If you need help drawing your graph, read "Resource Unit 4: Making Graphs."

Typically, a spring stretches in direct proportion to the amount of force applied to it. It returns to its original position when the force is removed. Such a spring is said to obey Hooke's law. Its behavior will graph as a straight line, so the graph can be used to predict the amount of stretch for any given amount of force.

☆ **10-4. Look at Figure 10-1 above again. How far would the spring be stretched by a force of 3.5 N?**

10-4. About 10 cm

But every spring has its limit. If a great force is applied, the spring will no longer keep its elastic properties. It won't spring back to its original shape. In fact, if the force is great enough, the spring will break.

Most springs (and most metals) behave as shown in Figure 10-2 below. The Hooke's law region is the extent of the straight line. After a certain point, called the *elastic limit*, Hooke's law is not valid. From that point, the stretch of a spring is no longer proportional to the force applied, and a curved graph results. At some further stress point, the spring breaks.

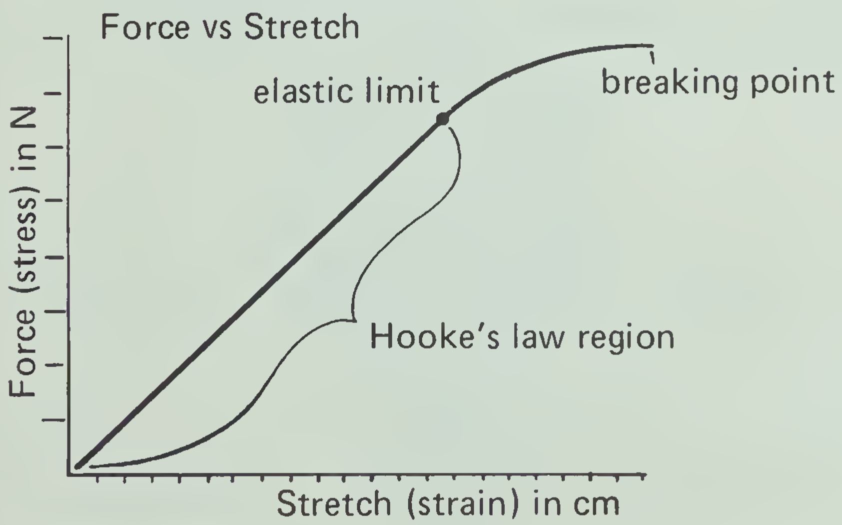


Figure 10-2

10-5. Treat the spring with care. Don't use a force greater than the elastic limit. Otherwise, you will stretch the spring out of shape or break it.

• 10-5. Rewrite the "Caution" on page 49, using the term *elastic limit.*

Several types of springs have been used in car suspension systems. Five of them are shown in Figure 10-3 below.

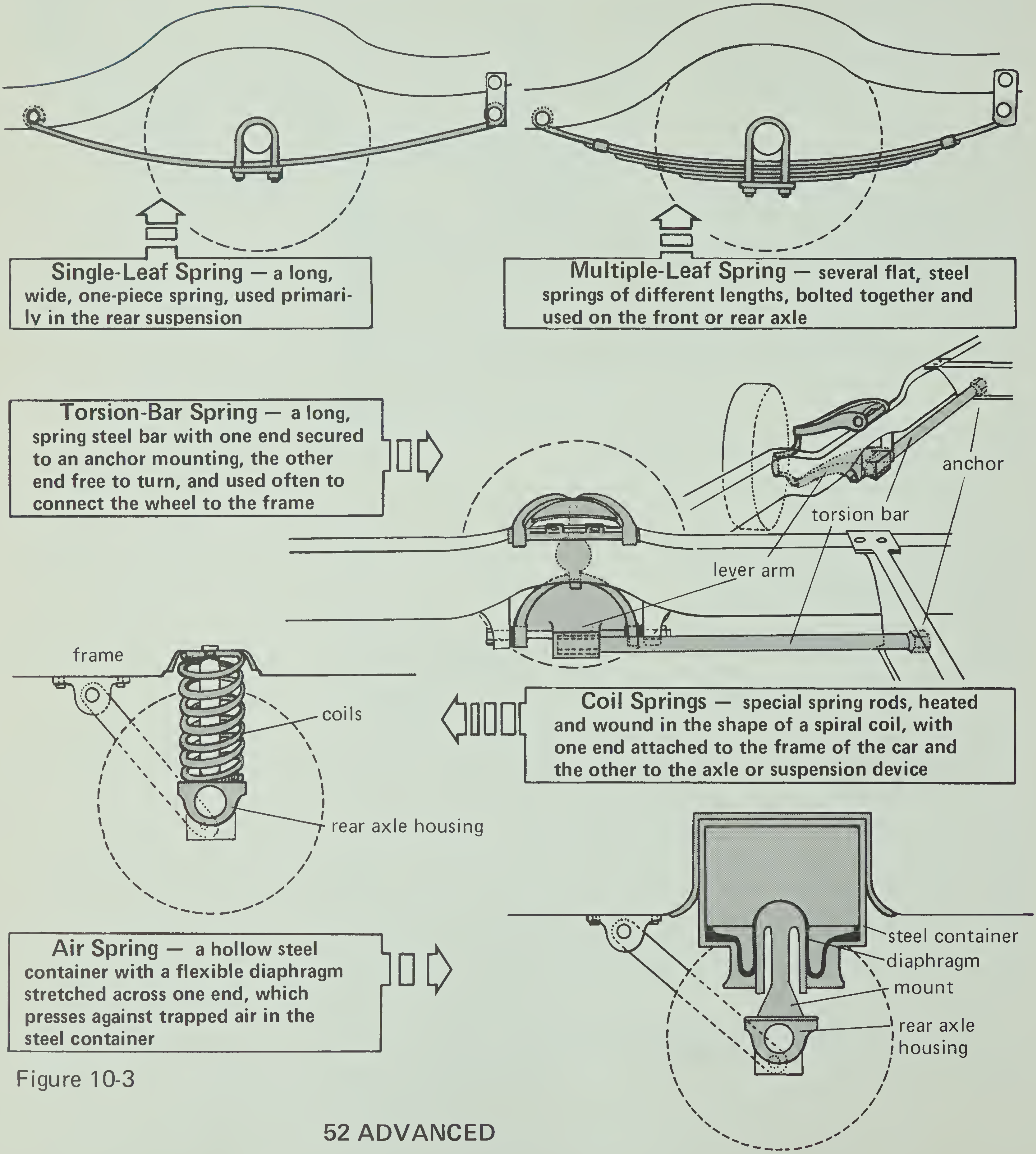
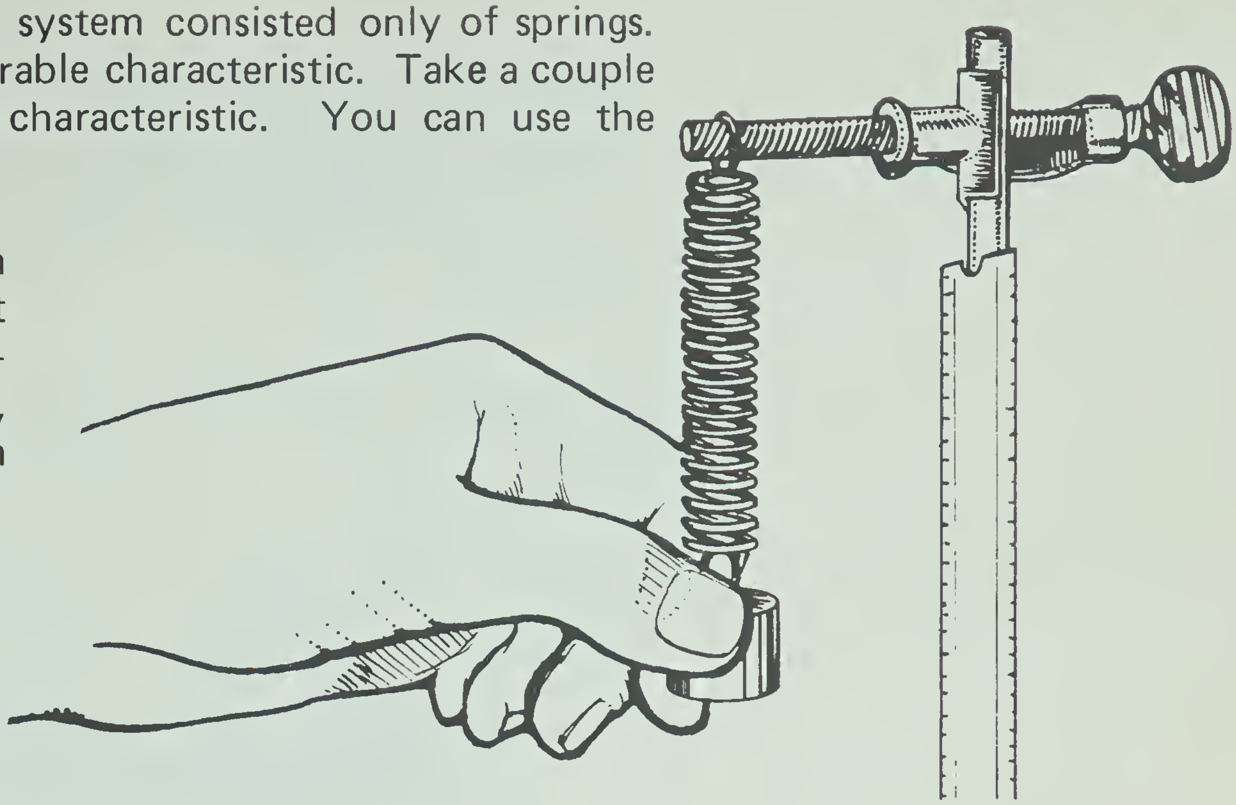


Figure 10-3

Suppose a car's suspension system consisted only of springs. It would have a highly undesirable characteristic. Take a couple of minutes to discover this characteristic. You can use the equipment you already have.

F. Put one of the weights on the spring. Pull the weight downward about 2.5 cm farther than its rest position, and then release it. Watch the action.



● 10-6. Describe the action of the weight and spring.

To keep a car from doing the same thing, shock absorbers are used. They stop this oscillatory motion.

☆ **10-7. How are the elastic properties of springs useful in car suspension systems?**

● 10-8. Why are shock absorbers used in car suspension systems?

☆ **10-9. What is elasticity?**

10-6. The weight goes up and down for quite a while.

10-7. The springs allow wheels to move up and down without transmitting jolts to the car body.

10-8. To damp oscillations

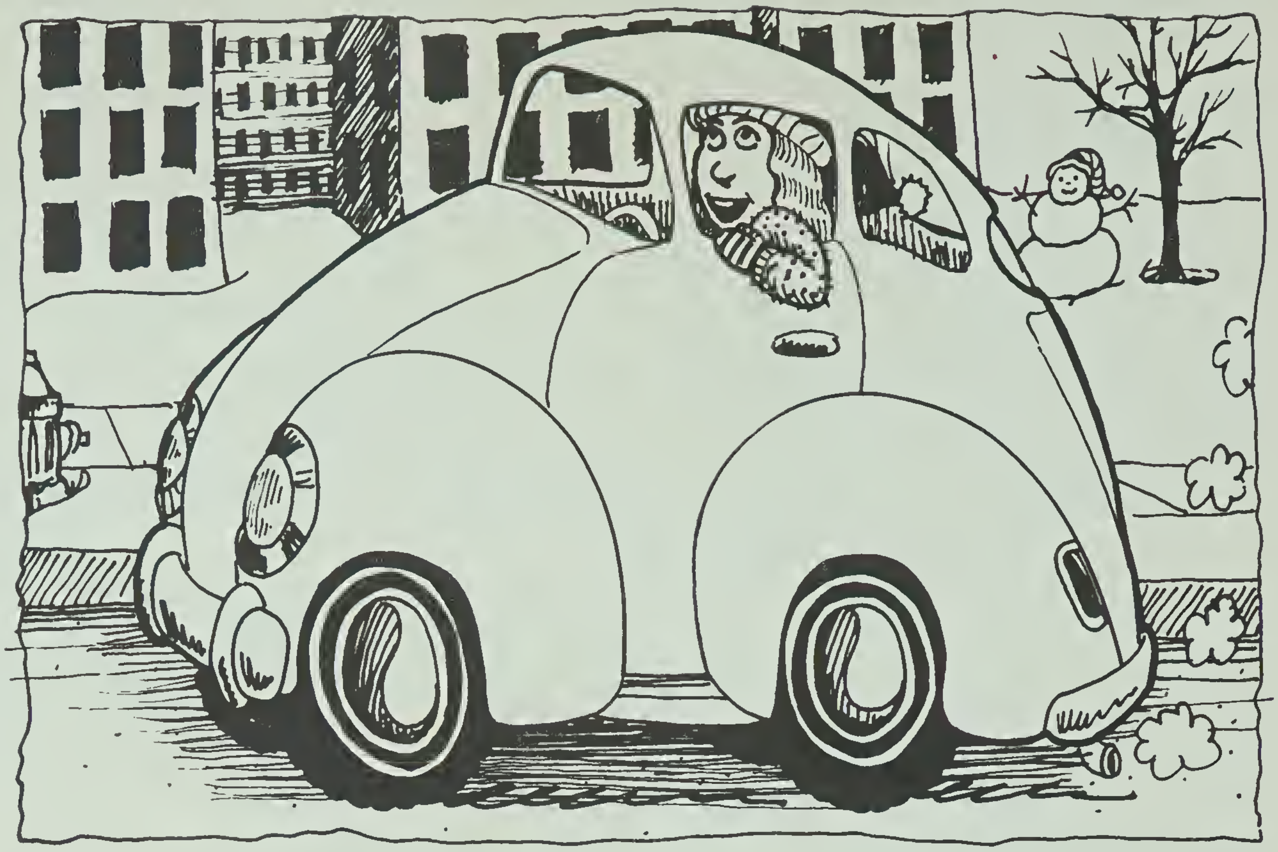
10-9. The tendency of a body when deformed to return to its original shape

ACTIVITY 11: EXPANSION AND CONTRACTION

It's 7:30 on a January morning, and the temperature is below freezing. You get into your car, start the engine, and pull away from the curb. Fuel burns in the cylinders to make the car go. In a few minutes the engine, like the car's interior, is comfortably warm.

ACTIVITY EMPHASIS: Expansion of metals due to heating is directly proportional to the increase in temperature. Piston rings accommodate for cylinder and piston expansion resulting from rising temperature.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.



In those few minutes, some parts of your car's engine have undergone large temperature changes. They have gone from temperatures below 0°C to temperatures well above 100°C. Among these parts are the pistons that move in the cylinders.

11-1. The burning of fuel in the cylinders

● 11-1. What causes the large temperature changes?

A piston and a cylinder have to fit together very precisely. If the tolerances between them are too small, the parts will wear too much and the engine will fail.

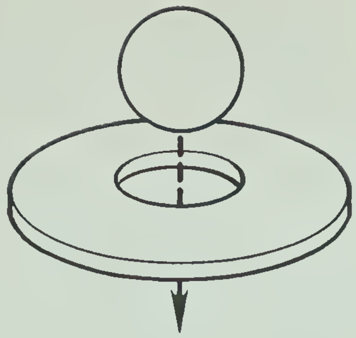
On the other hand, the tolerances must not be too great. If they are, compressed gases will leak past the piston in one direction and lubricating oil will leak past in the other. Both kinds of leaks cause poor engine performance and raise operating costs.

All of this has to do with expansion and contraction. Nearly everything expands when it's heated, including pistons and cylinders. How will this affect the tolerances between them? Will the space get larger or smaller? There's a simple way to find out. You'll need the following materials.

If available, commercial ball and ring apparatus may be used. See "Advance Preparations" for details. In any case, make certain that the ball will not pass easily through the hole in the washer at room temperature but falls through when the washer is heated.

safety goggles
steel ball, 14.3 mm in diameter
aluminum washer with 14.3 mm inside diameter
tongs or test-tube holder
Bunsen burner
asbestos pad
safety matches

A. Check to see whether the ball will pass through the hole in the washer.



• 11-2. When the ball and the washer are at room temperature, will the ball pass through the washer?

11-2. Not without forcing

• 11-3. Predict what will happen when the washer is heated. Will the hole get larger or smaller?

11-3. [Answers will vary. The hole will get larger, but students may fail to predict the correct answer at this point.]

CAUTION	Don't touch hot metal. It will burn even when it looks cool. Always use tongs. Don't put the hot metal pieces on any place that could be damaged by heat. Always set the hot pieces on the asbestos pad. Wear your safety goggles.

B. Put the burner in the center of the asbestos pad. Light the burner, and adjust it to a hot flame.

C. Use tongs to hold the washer by its edge in the flame. Heat it for about a minute. Then remove it from the flame.

D. Without touching the washer with your fingers, drop the ball into the hole in the washer.

• 11-4. When the washer is heated, what happens to the ball?

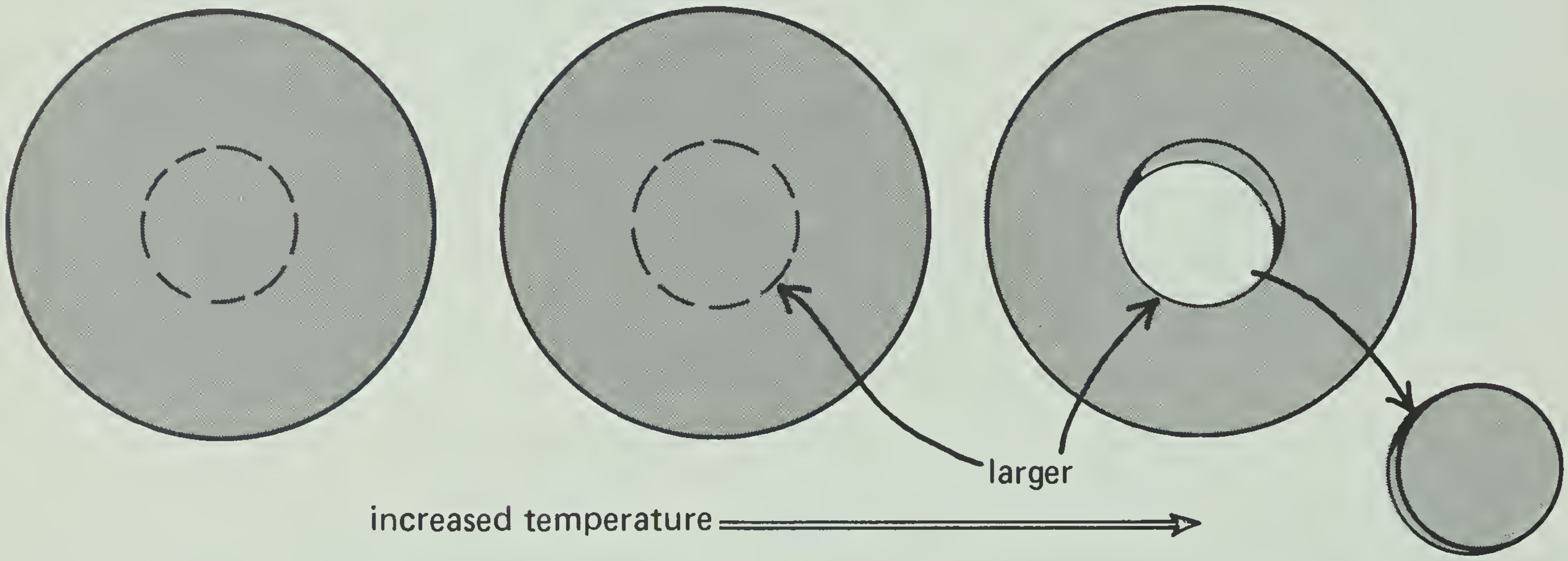
11-4. It falls through the hole in the washer.

☆ **11-5. When a metal washer is heated, does the hole in the center get larger or smaller?**

11-5. Larger

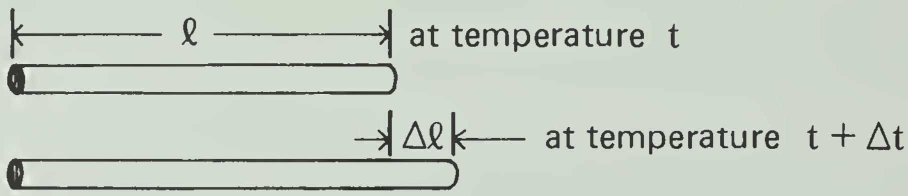
You might think that the hole in the washer should get smaller. After all, shouldn't the heated washer expand in all directions? One way to explain the actual result is as follows.

1. Imagine a solid piece of metal with no hole, but with a dotted circle drawn where the hole would be.
2. When the temperature increases, the dotted circle should get bigger because it is the outer edge of a piece of metal in the center.
3. If the center is cut out to make the hole, the same dotted line is the inner edge of the washer.



Over a wide range of temperature, the lengthwise expansion of most metals is directly proportional to the increase in temperature. The increase in length divided by the length of the bar times the increase in temperature is called a metal's *(thermal) coefficient of expansion*. See Figure 11-1 below.

The triangle Δ is the symbol for the Greek letter *delta*. It means "change in." So $\Delta\ell$ (read *delta ell*) means change (increase) in length. And Δt (read *delta tee*) means change (increase) in temperature.



$$\text{coefficient of expansion} = \frac{\Delta\ell}{\ell(\Delta t)}$$

where $\Delta\ell$ = change in length

Δt = change in temperature

Figure 11-1

11-6. 0.00002

● 11-6. Look at Figure 11-1 above. If, for a metal bar, ℓ is 1000 mm, $\Delta\ell$ is 0.02 mm, and Δt is 1°C, what is the metal's coefficient of expansion?

Like the steel ball and the aluminum washer, different engine parts (or different components of the same part) are often made of different metals. In general, different metals have different coefficients of expansion. The exact values have to be taken into account by engine designers.

Because of expansion differences, for example, pistons are not designed to have direct contact with cylinder walls. Rather, the pistons are fitted with piston rings that have contact. Figure 11-2 below shows a typical arrangement. Notice that each ring has a gap. Among other purposes, this gap can relieve heat expansion stresses that might otherwise crack the ring.

11-7. They get smaller. The inside spaces of the cylinders are like the hole in the washer, which gets smaller when cooled and larger when heated.

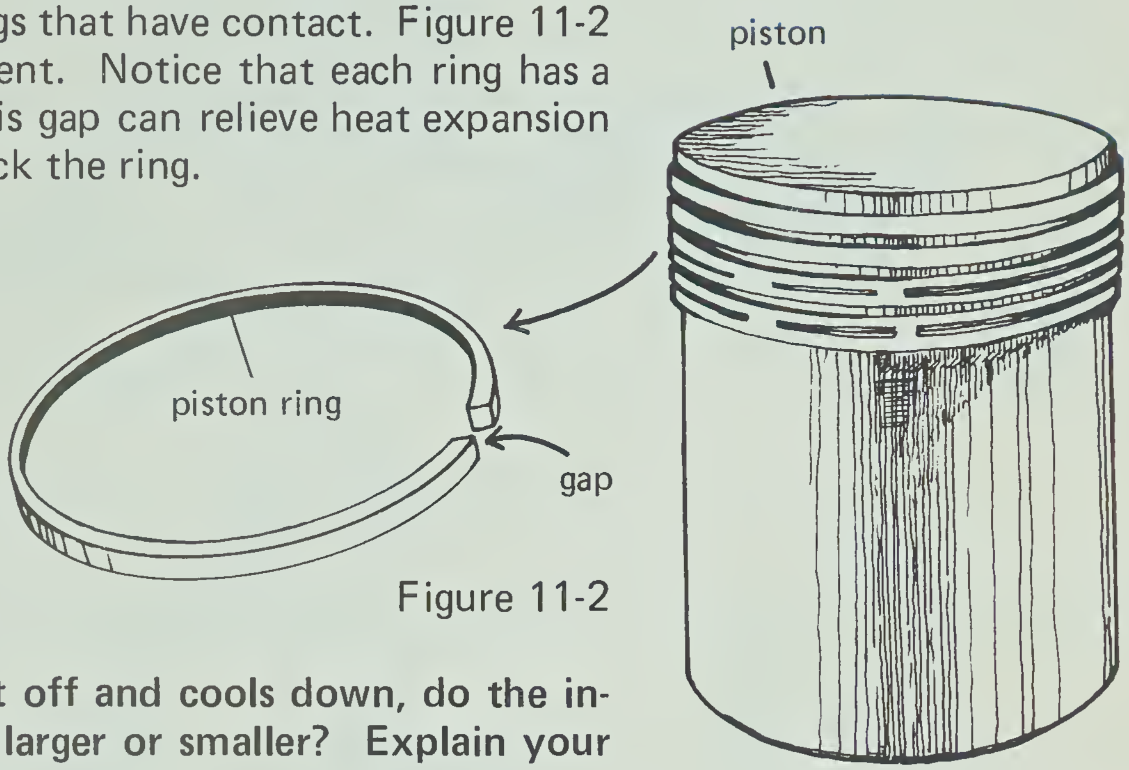


Figure 11-2

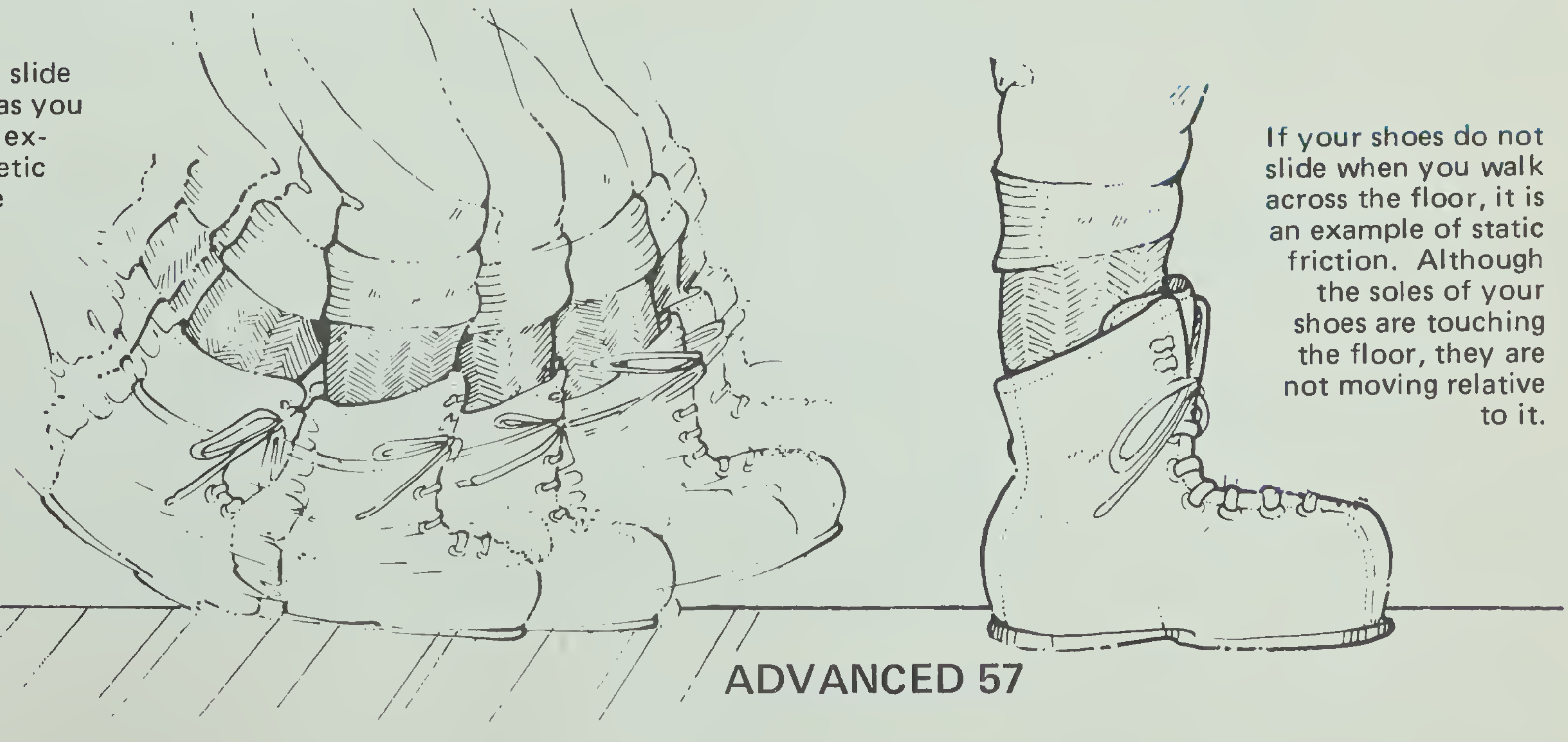
☆ **11-7. When an engine is shut off and cools down, do the inside spaces of the cylinders get larger or smaller? Explain your answer.**

ACTIVITY 12: FRICTION, FRIEND OR FOE?

ACTIVITY EMPHASIS: Static friction gives traction to surfaces and allows braking. Kinetic friction does not allow the driver much control over the car. The coefficient of friction is the ratio between the force of friction and the force normal to the surface.

Wherever two solid surfaces touch, there is friction. If the surfaces slide when they touch, the friction is called *sliding*, or *kinetic*, friction. If the surfaces do not move relative to each other, the friction is called *static* friction.

If your shoes slide on the floor as you walk, it is an example of kinetic friction. The sole of your shoe is moving relative to the floor. When you walk on ice, you try to keep this from happening.

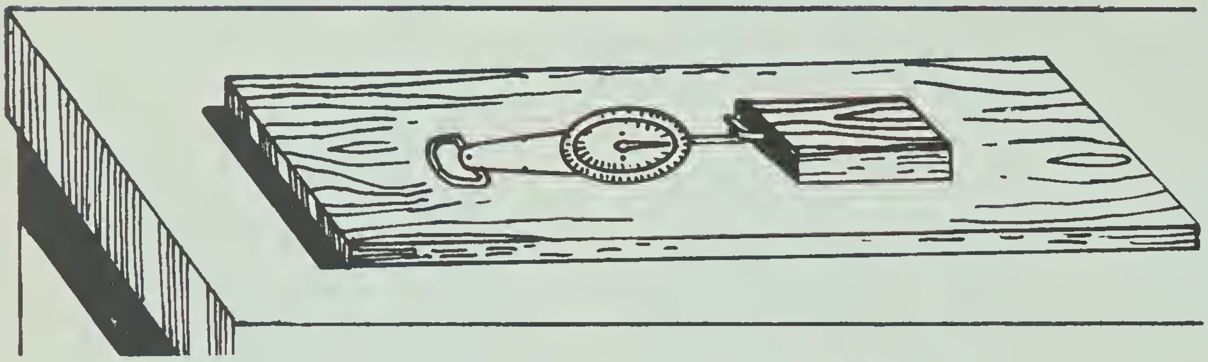


If your shoes do not slide when you walk across the floor, it is an example of static friction. Although the soles of your shoes are touching the floor, they are not moving relative to it.

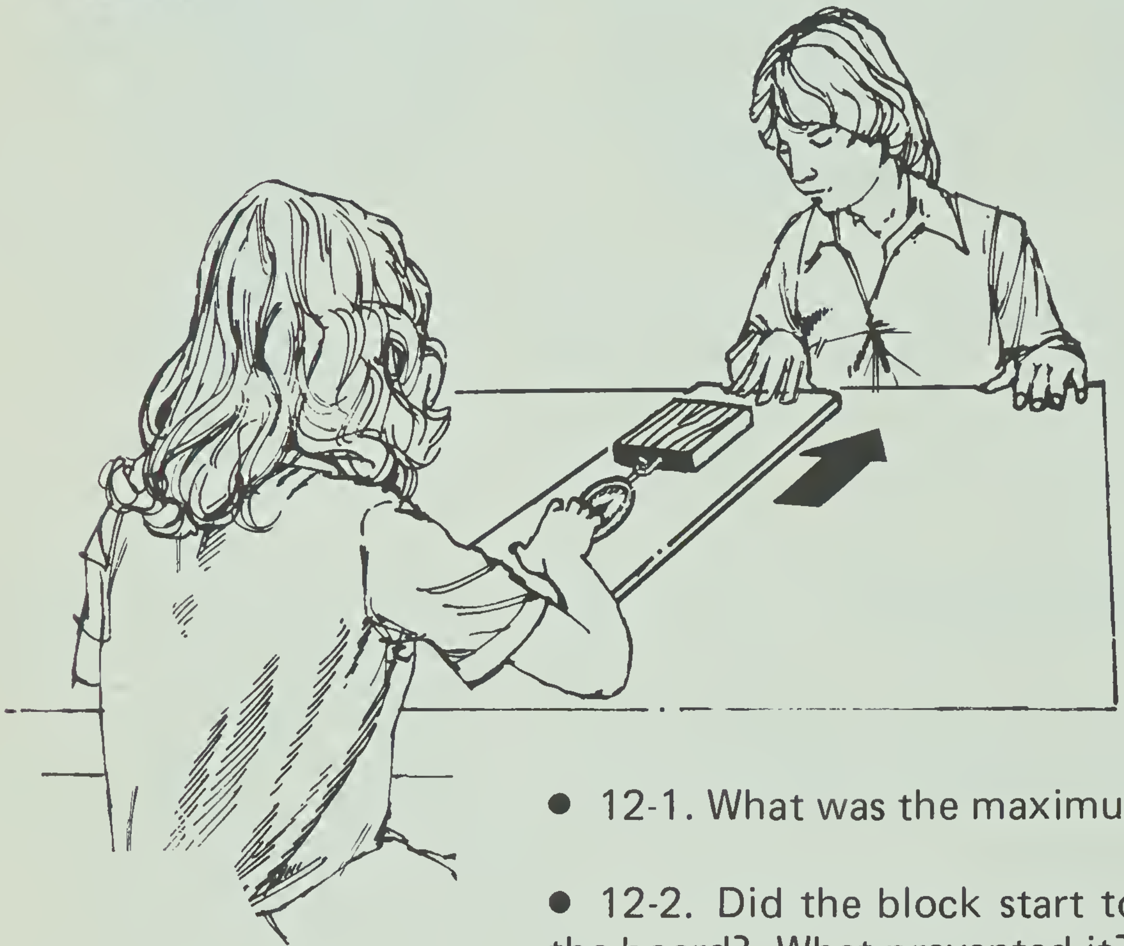
MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

You can easily see how both kinds of friction work. Get a partner and the following materials.

spring scale calibrated in newtons
wood block with hook in one end
wood board about 1 m long
half-kilogram mass



A. Lay the board flat on the table. Place the block at rest on the board. Attach the spring scale to the hook. You are going to move the board relative to the block. One person should hold the spring scale stationary and take the readings. The other person should move the board.



B. Move the board very slowly while holding the spring scale motionless. Keep noting the reading on the scale. Note how high the reading gets before the block starts to slide on the board. Then stop moving the board.

- 12-1. What was the maximum scale reading?

- 12-2. Did the block start to slide the instant that you moved the board? What prevented it?

12-1. [Answers will vary.]

12-2. No; friction

Any change in the motion of a body — whether in speed or in direction — is in response to a force. This is true whether the body is a wood block or a car or a baseball. You exerted a force on the board parallel to its surface. This caused it to move. Because the block moved too, the board must have also exerted a force on the block, a force parallel to its surface. This horizontal force between the board and the block was friction force.

12-3. Static friction force

- 12-3. While you were pulling on the board but before movement began, what kind of friction force existed?

C. Repeat Steps A and B. But this time continue to pull the board at a uniform speed after the block starts to slide on the board. Note the scale reading while the block is sliding.

- 12-4. What was the scale reading while the block was sliding?

12-4. [Answers will vary.]

- 12-5. Which scale reading was greater — the one when the block was sliding or the one when there was no relative motion?

12-5. The scale reading was greater when there was no relative motion.

While you were moving the board and the block was sliding on it, there still existed a force between the board and the block. This friction force was indicated by the scale reading.

- 12-6. With the board moving relative to the block, what kind of friction force existed?

12-6. Sliding, or kinetic, friction force

You should have seen that the static friction force was greater than the kinetic friction force. If you didn't see this, repeat Steps A, B, and C.

Think about what your findings mean as far as starting or stopping a car is concerned. One thing is that static friction forces are more effective than kinetic ones. In other words, don't slide your tires, either in stopping or in starting.

- 12-7. Does starting a car with squealing tires involve static friction or kinetic friction? Explain your answer.

12-7. Kinetic; the tires spin, sliding where they contact the road.

☆ **12-8. In normal driving, the road exerts friction force on the tires. Is this friction static or kinetic? Why?**

12-8. Static; in normal driving tires roll rather than slide.

What do these two kinds of frictional force depend on? Why do a car's tires skid in one situation and not in another? Use the apparatus to find out.

D. Set the block on the board again. This time place a half-kilogram mass on top of the block. Then measure the static and kinetic friction as you did in Steps A, B, and C.

● 12-9. How much was the static friction? The kinetic friction?

12-9. [Answers will vary.]

● 12-10. How do the friction forces on the weighted block compare with those on the unweighted block?

12-10. They are greater on the weighted block.

Apparently, friction increases with the weight of the object. This means that the tires of a large, heavy car press harder on the road than those of a light car, and they have more friction. That's good. Since the heavier car has more mass, a greater frictional force is required to change its motion (for any given amount of change).

In the winter, with snow and ice on roads, some car owners carry extra weight in the trunk. This weight can be in the form of bricks or cement blocks.

12-11. The rear tire friction would be increased.

● 12-11. What would be the effect on tire friction of a heavier weight on the rear of the car?

But extra weight is not the only way of increasing friction. Some drivers in icy climates carry a pail of sand in the back of the car for use in getting started on slippery roads.

You can see the effect of changing the road surface with a simple investigation. You will need the following additional materials.

material with rough surface (carpet or sandpaper)
material with smooth surface (plastic or metal)

E. Set the block on the rough surface. Measure the static and kinetic friction as you did in Steps A, B, and C.

F. Repeat the measurement of static and kinetic friction with the block on the smooth surface.

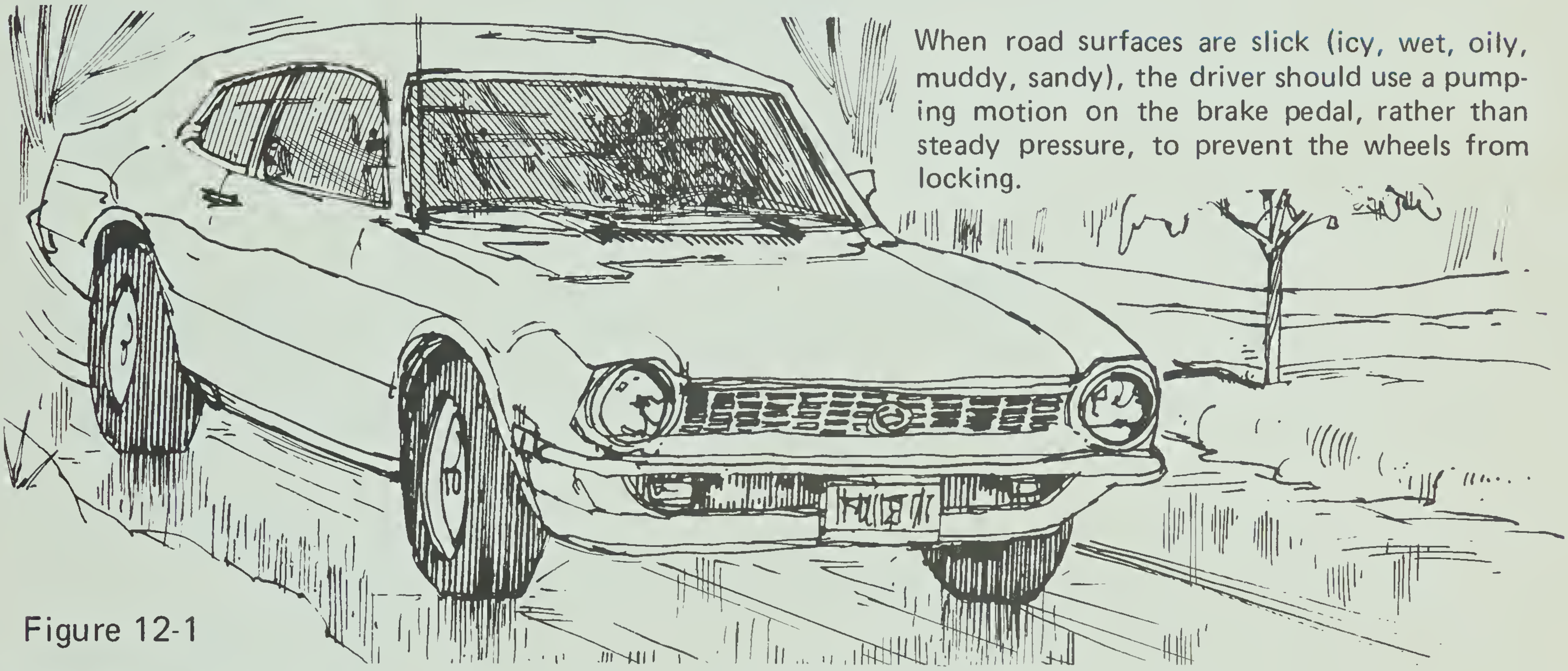
- 12-12. In which case was the static friction force greater?

12-12. With the rough surface

- 12-13. In which case was the kinetic friction force greater?

12-13. With the rough surface

When road surfaces are slick, it is difficult to get a car started. And it also requires care to get it stopped.



When road surfaces are slick (icy, wet, oily, muddy, sandy), the driver should use a pumping motion on the brake pedal, rather than steady pressure, to prevent the wheels from locking.

Figure 12-1

☆ **12-14. Why is the advice given in Figure 12-1 above good advice about stopping on slick roads? Explain your answer in terms of friction forces.**

12-14. When the road is slick, maximum static friction force may be quickly exceeded so that sliding begins. Letting up on the pedal allows sliding to stop. Static friction comes back.

Friction forces are necessary to the operation of a car. They allow it to start moving, to be controlled on the road, to turn corners, and to stop. In fact, without the friction inside the brake mechanism, the wheels couldn't be slowed or stopped quickly. In all these cases, friction is a friend.

But when the tires slide on the road surface or when engine parts rub together, heat is produced and energy is wasted. In those cases, friction is a foe.

ACTIVITY EMPHASIS: According to the kinetic molecular theory, the average kinetic energy of a gas (as measured by temperature) will increase as the gas is compressed. The diesel engine uses hot air instead of a spark plug to ignite the fuel.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

ACTIVITY 13: A DIESEL'S WORK LOAD

In the past, very few cars had diesel engines. Diesels were used almost entirely in heavy-duty vehicles — trucks, buses, and trains. But since diesels have some economic advantages over gasoline engines, they are becoming more popular with car manufacturers and buyers.

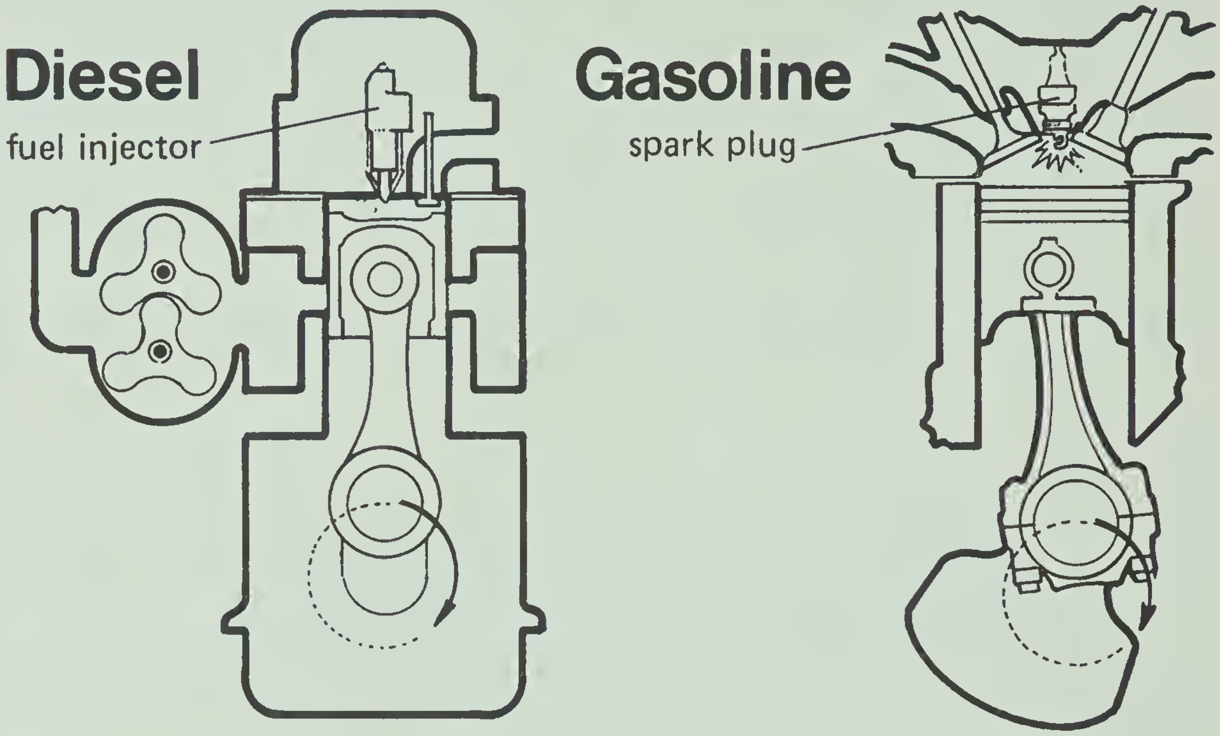


Figure 13-1

13-1. The diesel lacks a spark plug.

● 13-1. Look at Figure 13-1 above. What common part does a gasoline engine use to ignite the fuel—air mixture that is lacking in the diesel engine?

Diesels get along without spark plugs because they can use the heat of compression to ignite the air—fuel mixture. To see how this is possible, consider these facts.

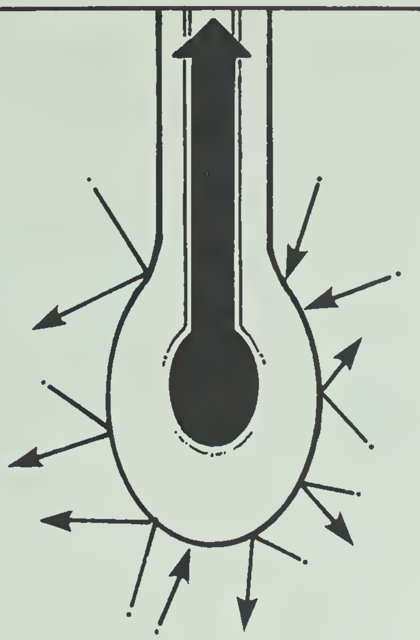
1. Air—fuel ignition will occur in an engine cylinder when the temperature reaches a certain level (in a diesel, about 500°C) even without a spark.

2. Air temperature can be raised by increasing the kinetic energy of air molecules (their energy of motion).

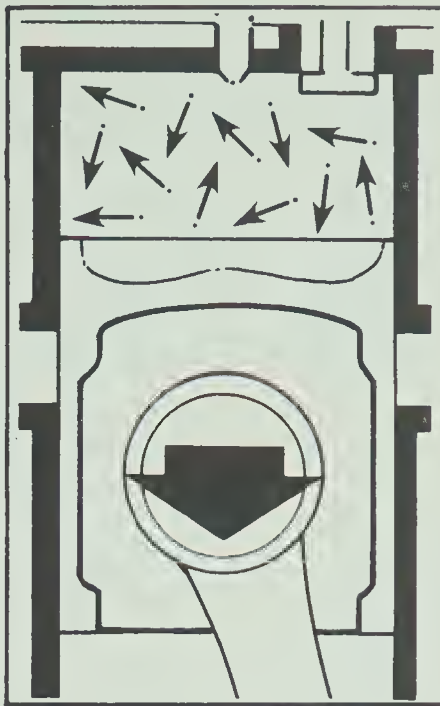
3. The kinetic energy of air molecules can be increased in several ways. One way is by compression.

Facts 2 and 3 above both mention the kinetic energy of air molecules. Kinetic energy is energy of motion. Thus, those facts are talking about moving air molecules.

According to the kinetic molecular theory, the motion of the molecules of a gas affects both the temperature of the gas and the force that the gas exerts on a container.



The rapidly moving molecules strike the thermometer bulb, giving energy to the mercury. The height the mercury climbs is an indication of the kinetic energy of the molecules.



The rapidly moving molecules exert a force on the piston, cylinder walls, and head. The more rapid the motion of the molecules, the greater the force exerted.

Fact 3 (page 62) needs to be explained further. Scientists have determined that the kinetic energy (E_k) of air molecules is related to both their mass (m) and their speed (v).

Average kinetic energy= ½ × mass × speed^2

or

$$E_k = \frac{mv^2}{2}$$

• 13-2. To change the kinetic energy of a molecule, you must change either of two things. What are those two things?

13-2. Mass and speed

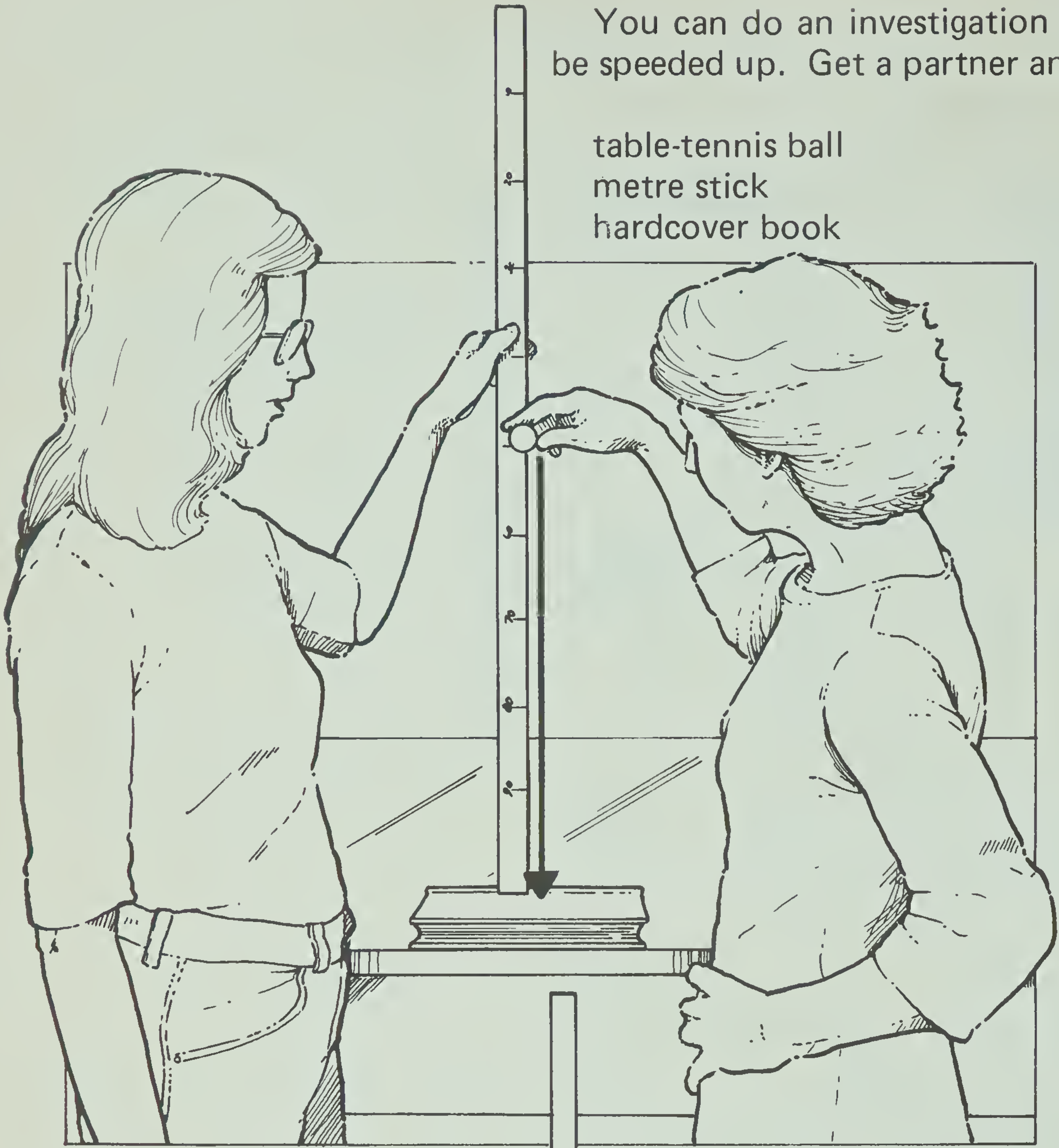
Inside an engine, it isn't possible to change a molecule's mass significantly. But it is possible to change a molecule's speed. Notice, too, that average kinetic molecular energy depends on the square of the speed.

• 13-3. If the speed of air molecules is doubled, how is their average kinetic energy affected?

13-3. It is increased by a factor of 4 (2^2).

You can do an investigation to understand how molecules can be speeded up. Get a partner and the following items.

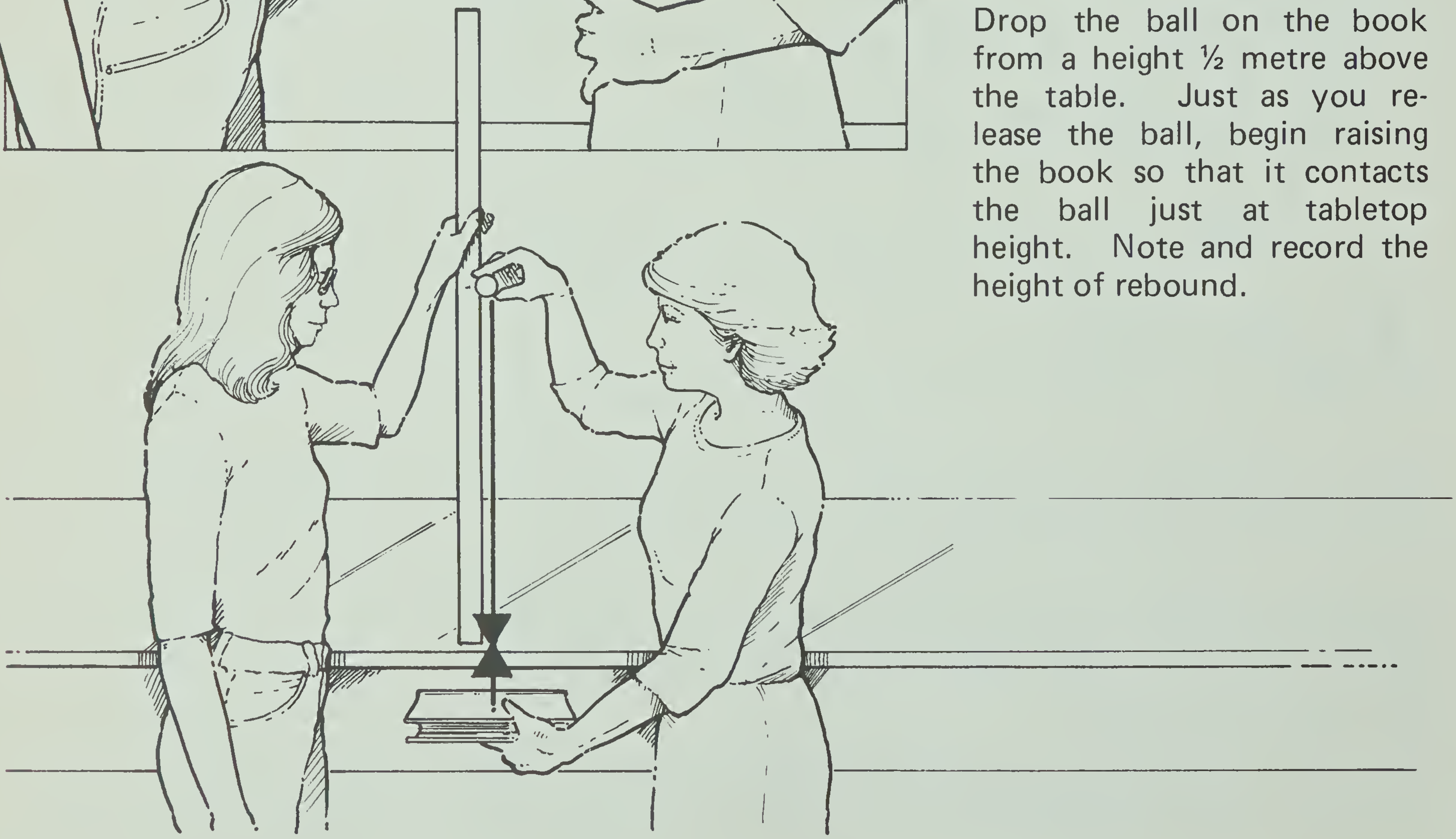
table-tennis ball
metre stick
hardcover book



A. Put the book on a table. Have your partner hold the metre stick vertically on the book, as shown.

B. Hold the table-tennis ball ½ metre above the top of the book, and drop it on the book. Note the height of rebound. Record that figure in your notebook.

C. Now hold the book a bit below the level of the table-top. Stand the metre stick on the table edge, as shown. Drop the ball on the book from a height ½ metre above the table. Just as you release the ball, begin raising the book so that it contacts the ball just at tabletop height. Note and record the height of rebound.

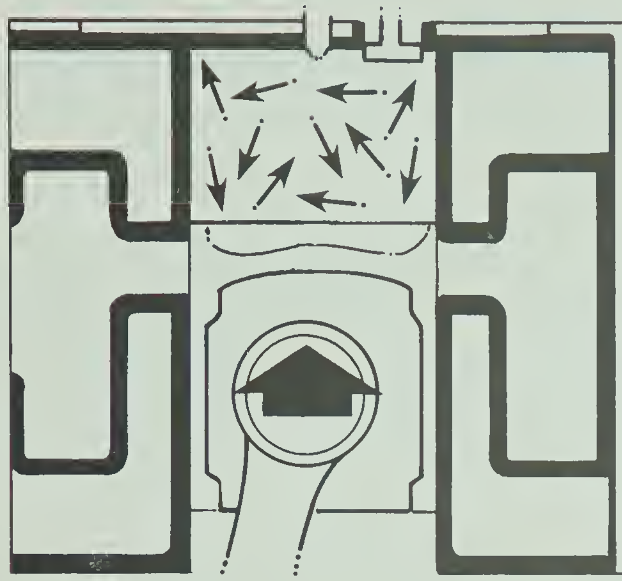


• 13-4. The higher the ball rebounded, the faster it was moving as it left the top of the book. Which time was the ball moving faster — when it left the book on the table or when it left the moving book?

13-4. When it left the moving book

• 13-5. Which time did the ball have more kinetic energy — when it was moving slower or when it was moving faster?

13-5. When it was moving faster



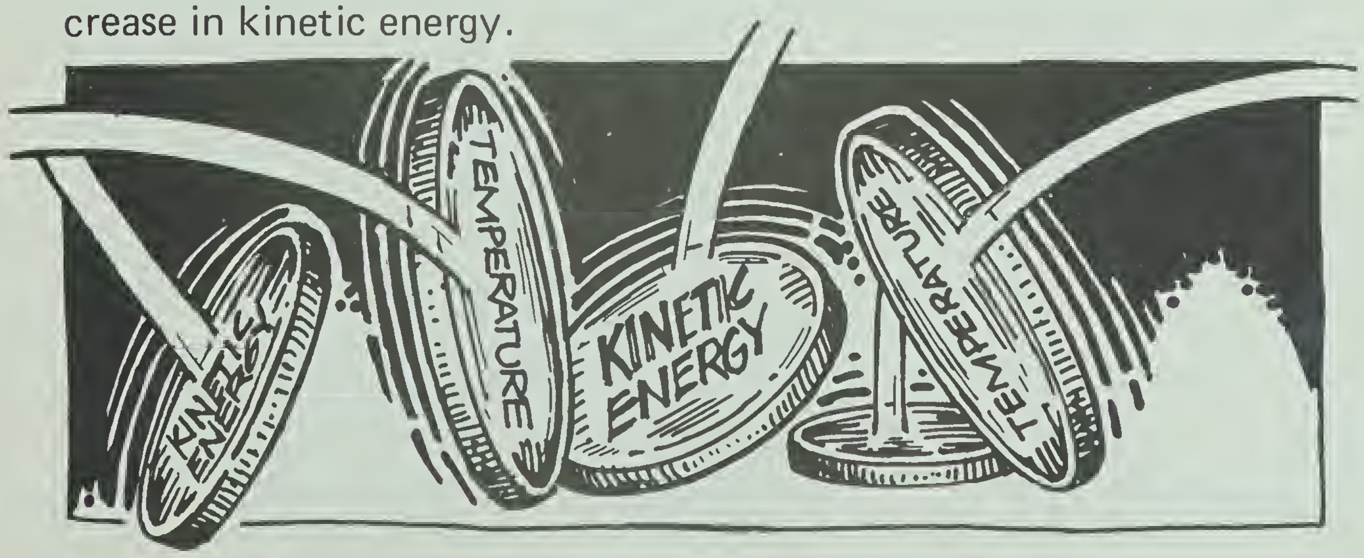
As the piston in the cylinder of a diesel engine starts its compression stroke, it begins to increase the speed of air molecules. As the speed increases, the molecules heat up.

☆ **13-6. When do air molecules have greater kinetic energy — during the intake stroke or at the end of the compression stroke? What measurable thing allows you to tell?**

13-6. At the end of the compression stroke; higher temperature

Both gasoline engines and diesel engines compress the gases on the compression stroke. But the compression is far greater with the diesel engine. The heat of compression is also greater — greater, in fact, than the ignition temperature for diesel fuel. So at the top of the compression stroke, a measured amount of diesel fuel is sprayed into the cylinder. It burns immediately, releasing as heat the chemical energy that is stored in the fuel.

And this brings up the other side of the energy coin. When air molecules increase in kinetic energy, they increase in temperature. And when air molecules increase in temperature, they increase in kinetic energy.



It's true that speeding up the air molecules heats them up enough to cause ignition. It's also true that heating the air molecules by ignition speeds them up still more. (That's how an internal combustion engine can give motion to the vehicle!)

13-7. Just after ignition

● 13-7. When will the air molecules have greater kinetic energy — near the end of the compression stroke or just after ignition?

13-8. The ball dropped from 1 m

● 13-8. Return to the table-tennis-ball "molecule" again. Which will bounce higher — a ball dropped from ½ metre or one dropped from 1 metre?

The ball with the longer drop will be moving faster on impact. This is shown by the fact that it rebounds farther. (You might want to try that for yourself.) The ball with the greater speed of impact has more kinetic energy. It can do more work — that is, it can apply more force to an object to make the object move.

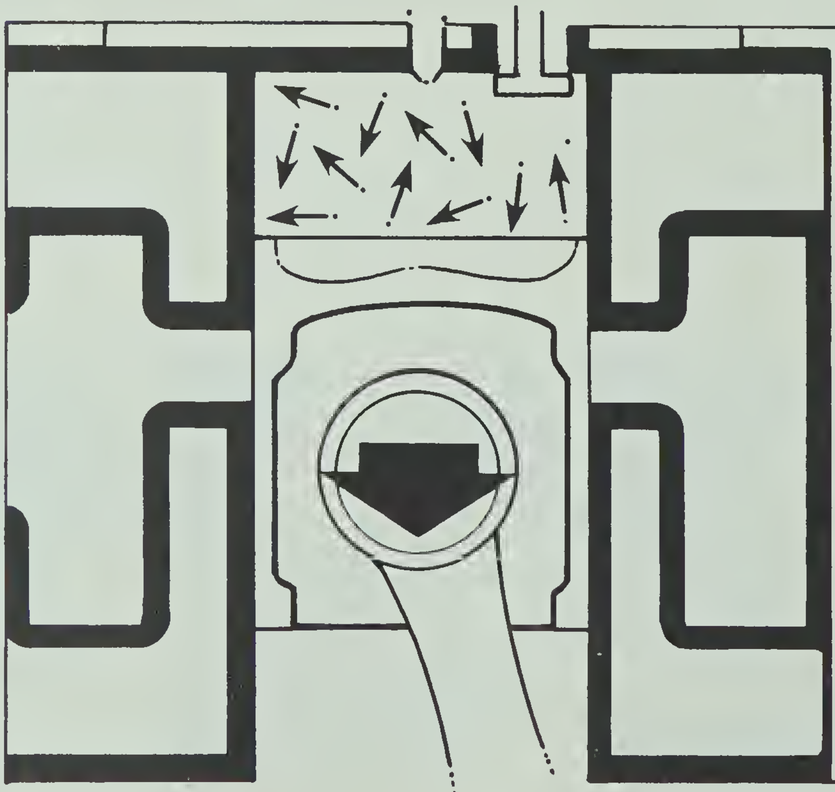
13-9. During the power stroke, gas molecules exert a force against the piston, driving it down.

☆ **13-9. According to the kinetic molecular theory, how do the gas molecules do work against the piston?**

A diesel's greater compression lets it get more energy from its fuel than a gasoline engine does. A diesel also causes less hydrocarbon pollution. And diesel fuel is cheaper than gasoline. But a diesel is also heavier and more expensive than a gasoline engine. And it has a more complicated fuel injection system.

13-10. The piston applies force against air molecules.

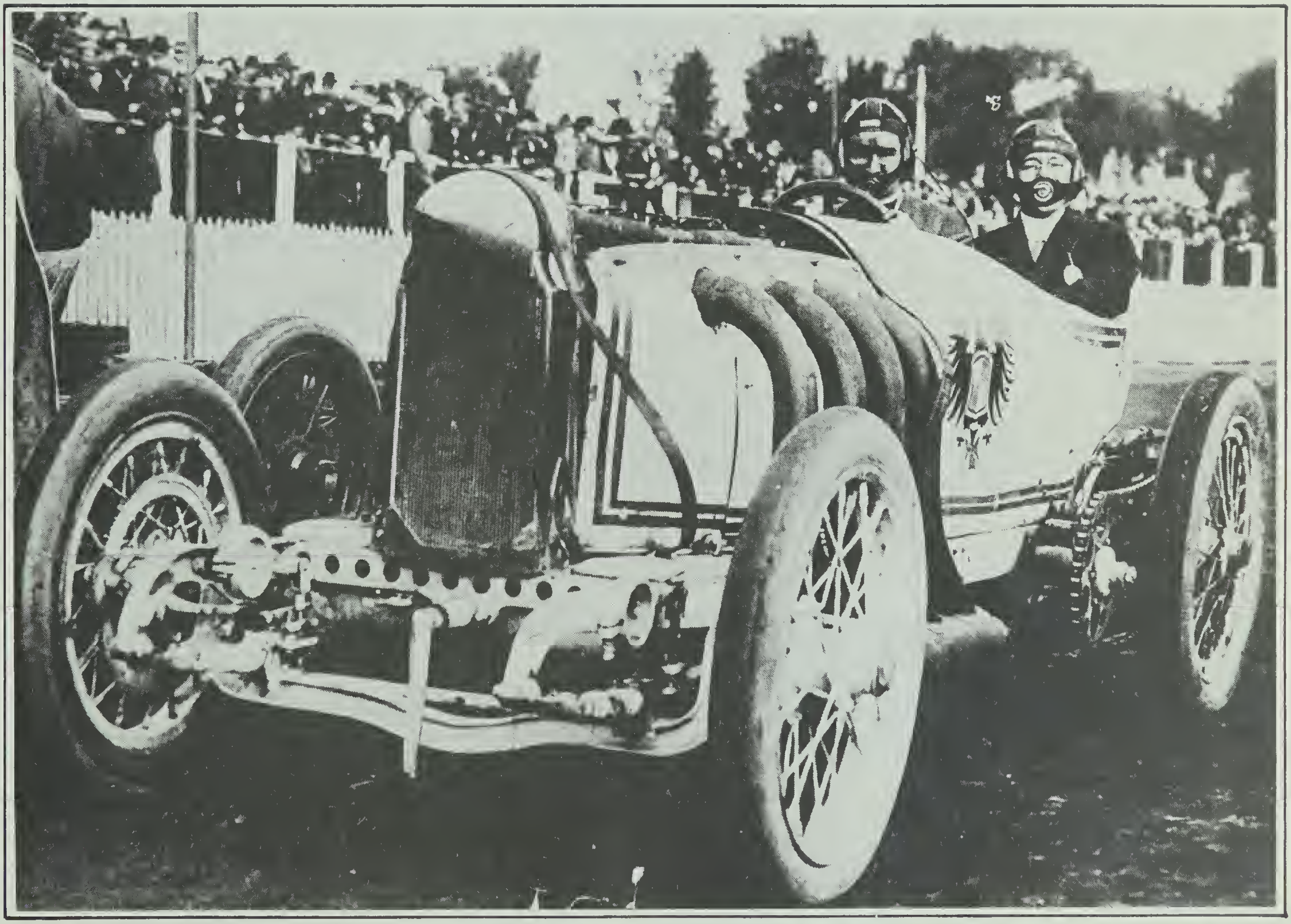
● 13-10. During the compression stroke, what does work (applies force) against what?



During compression, the piston does work against the air molecules, imparting kinetic energy to them. This situation is reversed during the power stroke after ignition.

EXCURSION

ACTIVITY 14: PLANNING

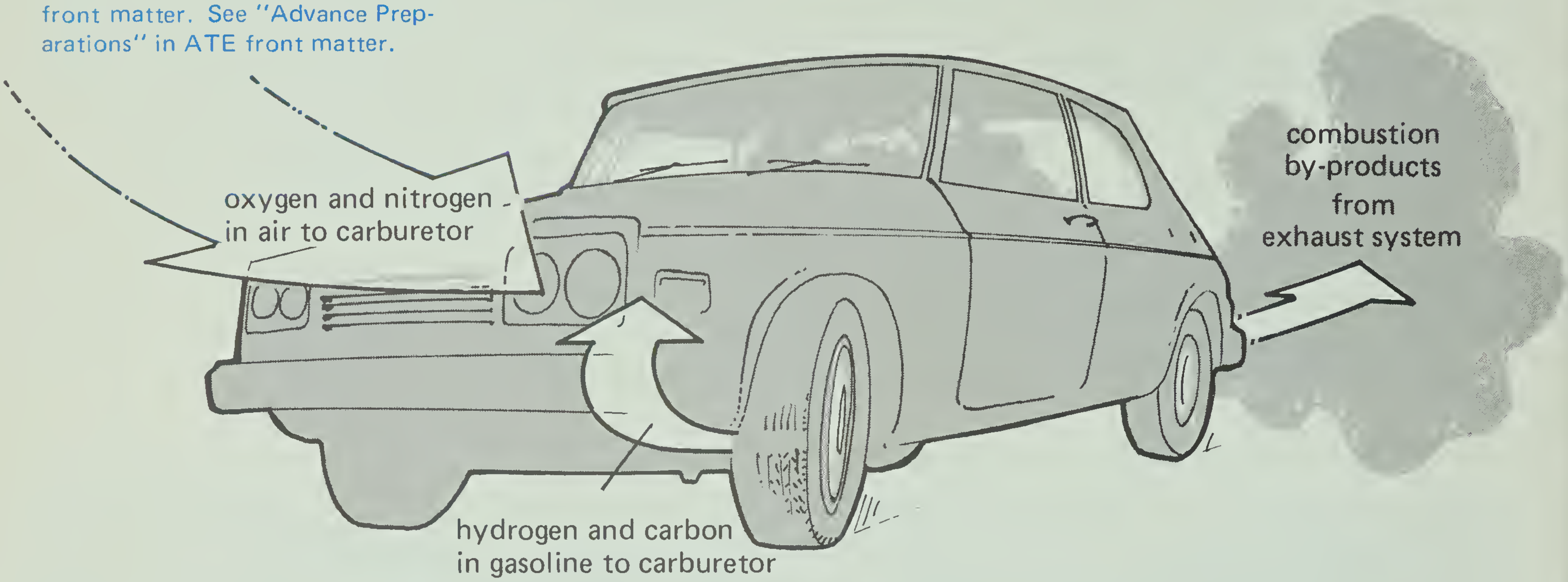


ACTIVITY EMPHASIS: Incomplete burning of hydrocarbons causes air pollution. A catalytic converter is one way of reducing this pollution.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

ACTIVITY 15: DON'T POLLUTE!

A car engine takes in air and gasoline through the carburetor. The mixture burns in the cylinders. The products of this burning are sent out the exhaust system and back into the air.



Air and gasoline are mixtures of fairly simple substances. Thus, their combination shouldn't be too complicated.

15-1. Oxygen and nitrogen

● 15-1. What are the two main substances that make up air?

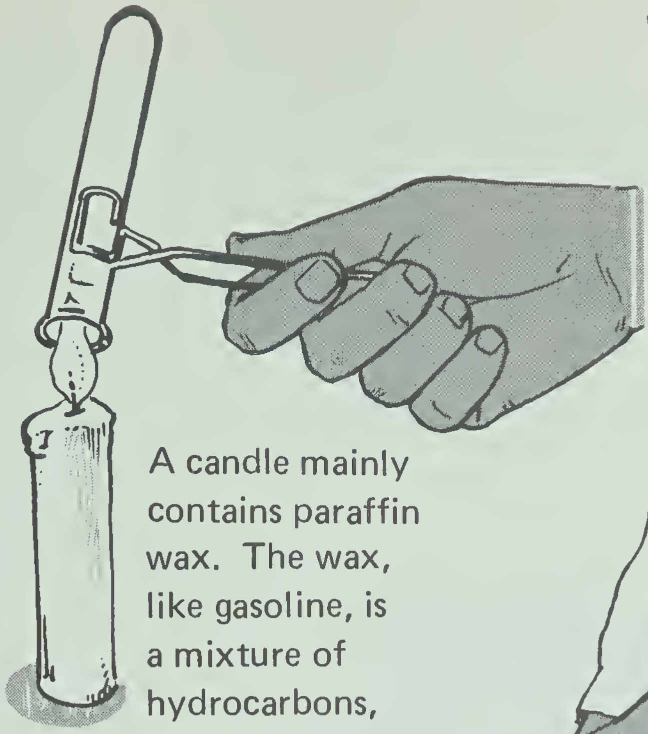
Gasoline is a mixture of compounds called *hydrocarbons*. Hydrocarbons are made up of hydrogen and carbon. So the combination of air and gasoline involves mainly four separate substances – oxygen and nitrogen from the air and hydrogen and carbon from gasoline. If all the gasoline burns completely, the exhaust system releases only harmless water vapor, carbon dioxide, and nitrogen into the air.

Hydrogen plus oxygen gives water vapor. Carbon plus oxygen gives carbon dioxide. Nitrogen passes through without change.

You can see how these substances combine in a simple investigation. You will need the following materials.

safety goggles
candle
safety matches
test tube and cork
test-tube holder
10 ml of limewater

A. Light the candle. Using the test-tube holder, put the test tube over the flame. Keep the flame inside the mouth of the test tube for about half a minute.



A candle mainly contains paraffin wax. The wax, like gasoline, is a mixture of hydrocarbons, but in solid form.

B. Quickly, insert the cork in the test tube. Turn the test tube upright. Blow out the candle. Then examine the inside of the test tube.

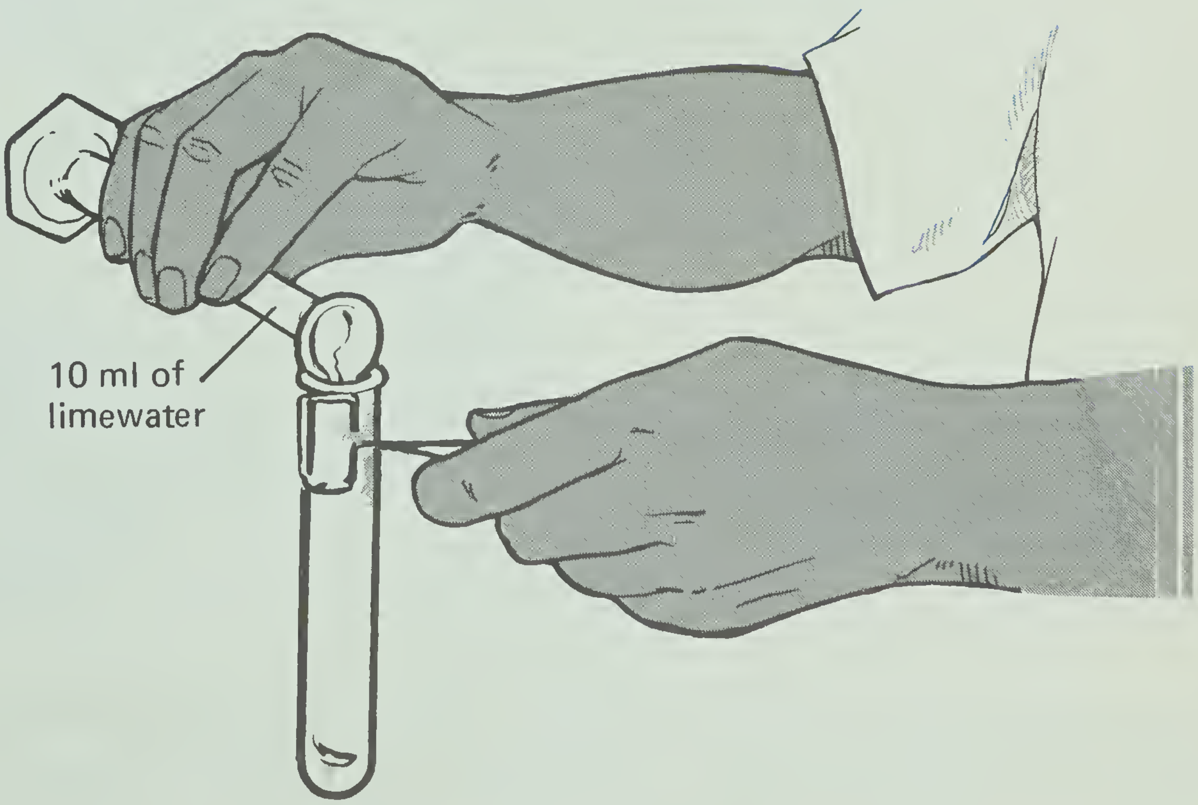
● 15-2. Describe the appearance of the inside of the test tube.

15-2. There is a black substance near the mouth of the test tube, a clear film on the sides of the test tube, and smoke in the test tube.

You should have had no trouble seeing the visible results of the burning hydrocarbons. The inside of the test tube is steamed up with tiny droplets. The hydrogen in the fuel combined with the oxygen in the air to form water.

Was carbon dioxide formed? You can find out very easily. If limewater is shaken in the presence of a concentration of carbon dioxide, it turns milky white.

C. Keeping the test tube upright, remove the cork. Add about 10 ml of clear limewater. Replace the cork. Shake the test tube well.



15-3. Carbon dioxide is present in the test tube.

● 15-3. What does the limewater test tell you?

There is another substance you can see in the test tube. When carbon and hydrogen (hydrocarbons) burn completely, no solid remains. The black, sooty smudge and the smoke, if any, were really caused by lack of burning. Some smoke is made up of tiny, solid particles of unburned fuel floating in air.

15-4. Carbon

● 15-4. What is the black substance in the test tube?

The solid carbon is really a major culprit in pollution. If it doesn't burn, it pollutes as a black soot or smoke. If it burns partially, it forms carbon monoxide. However, if it burns completely, it forms carbon dioxide and that's all right.

Paraffin wax is a mixture of hydrocarbons of the alkane series — the same series that includes hexane, heptane, and octane, the principal ingredients of gasoline. The alkane series is made up of saturated hydrocarbons, so called because of the single covalent bonds between atoms of carbon and hydrogen.

Nitrogen and carbon monoxide are also present in the test tube. At the temperature of a candle flame, nitrogen is not changed. And with unburned carbon showing up, it is reasonable to believe that there would be partially burned carbon monoxide as well.

One of the first steps in getting rid of these polluting substances can be taken right at a car's engine. Air is pumped into the exhaust manifold. It mixes with the hot exhaust gases from the engine and burns some of the unburned or partially burned fuel. The gases then go out the exhaust pipe. Look at Figure 15-1 below.

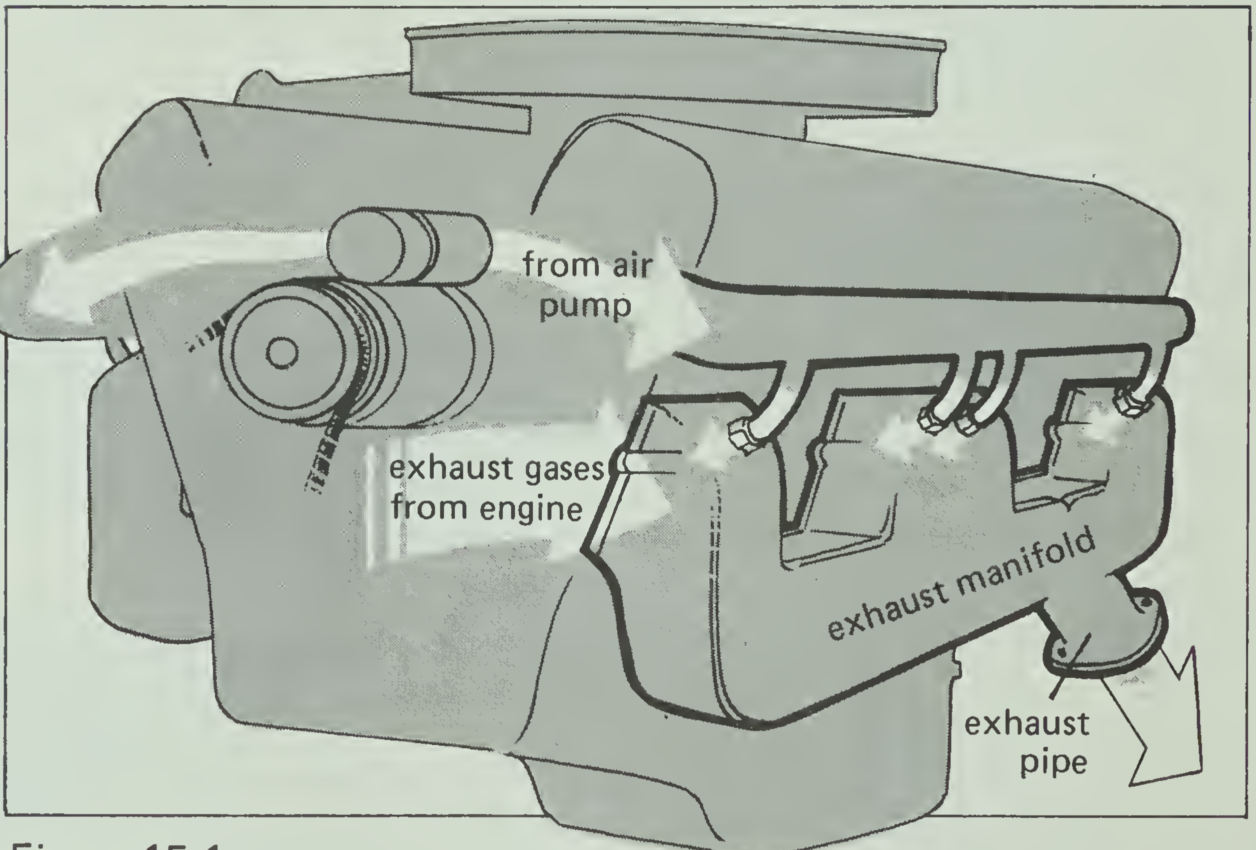


Figure 15-1

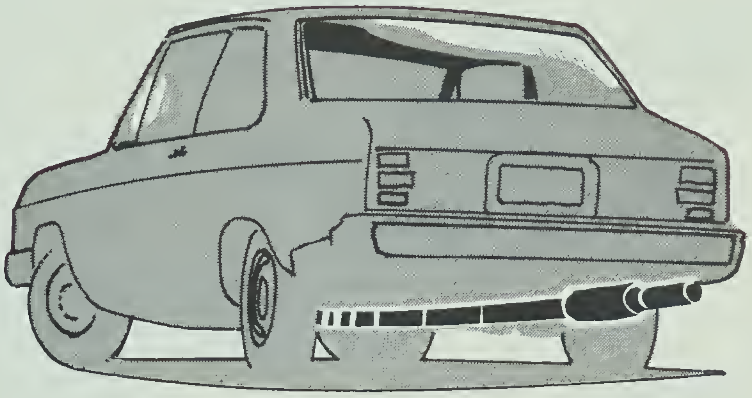
15-5. Carbon dioxide and water vapor

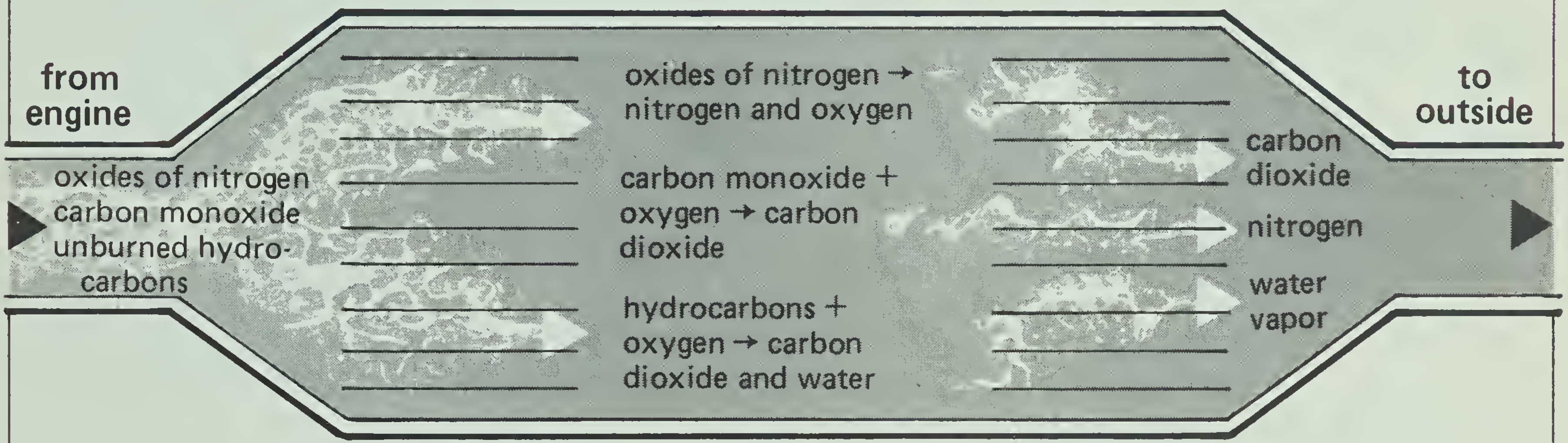
☆ **15-5. When hydrocarbons burn completely, what are the products?**

The inside of an operating cylinder gets much hotter than a candle flame. At high temperatures and pressures, nitrogen does combine with oxygen to form pollutants, called *oxides of nitrogen*. To combat this, a catalytic converter may be used.

Metals such as platinum, palladium, or even copper, nickel, and chromium can speed up some chemical reactions. In one of these reactions, oxygen is stripped from the oxides of nitrogen to leave harmless oxygen and nitrogen.

Those same metals in the catalytic converter can also aid oxygen to react with any carbon monoxide or unburned hydrocarbons that remain. This changes the carbon monoxide to carbon dioxide and the hydrocarbons to carbon dioxide and water vapor.





Catalytic Converter

15-6. What is the difference between what a catalytic converter does to oxides of nitrogen and what is done to carbon monoxide to reduce pollution?

15-6. With oxides of nitrogen, the oxygen is separated from the nitrogen. With carbon monoxide, oxygen is combined with the carbon monoxide to form carbon dioxide.

Catalytic converters can be damaged by tetraethyllead that is added to gasoline to stop knocking. Therefore, cars equipped with converters must use unleaded gasoline. Otherwise, the converter will stop operating.

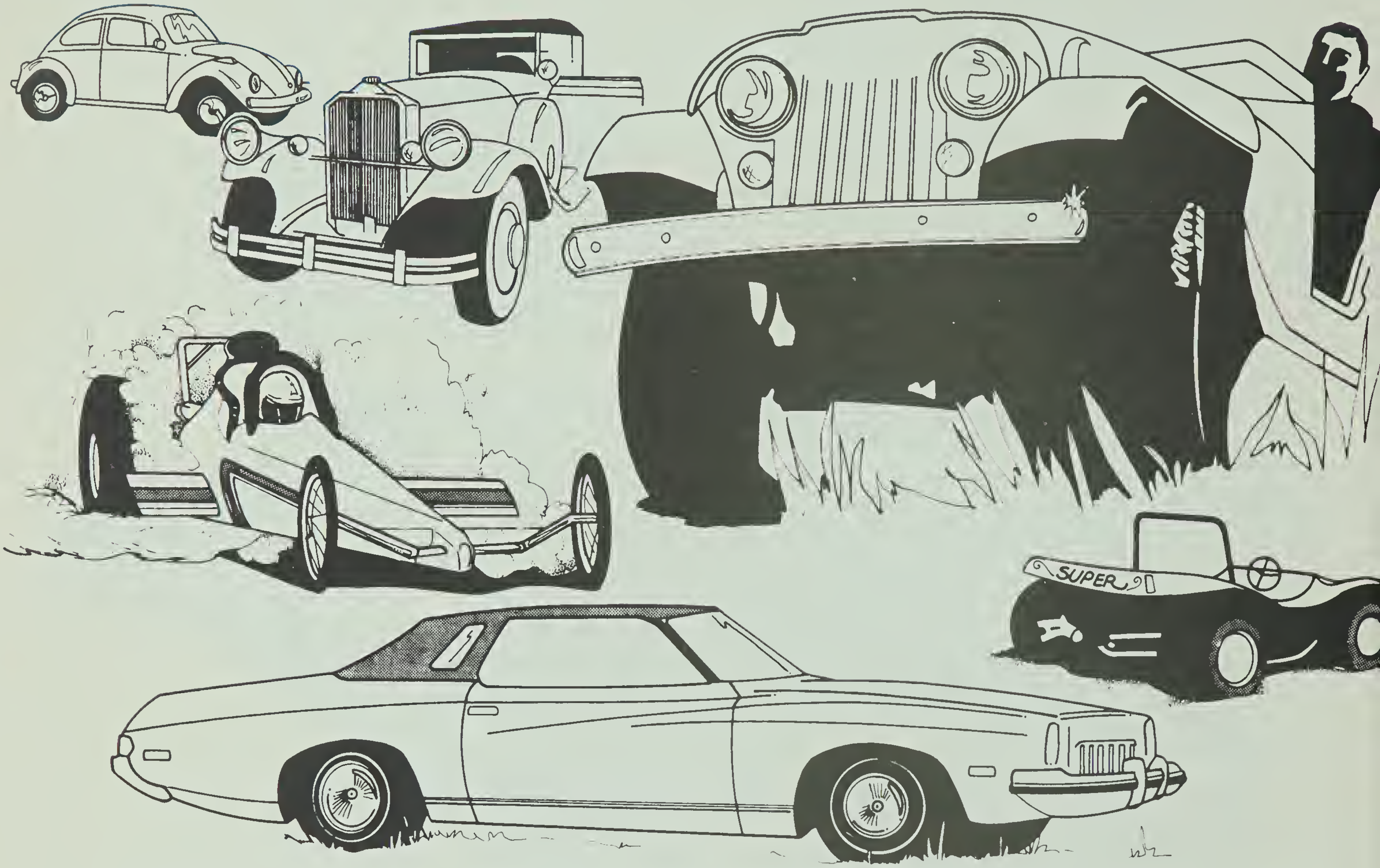
15-7. Why must newer cars use unleaded gasoline?

15-7. To keep from damaging the catalytic converter

ACTIVITY EMPHASIS: Engine displacement is the volume that all the pistons move through in a single stroke. Three methods of describing engine power are SAE (Rated), Indicated, and Brake. Brake power is the most practical standard of comparison. Compression ratio describes air–fuel compression and indicates the gasoline octane rating appropriate for that engine.

ACTIVITY 16: MY CAR'S BETTER THAN YOURS

My car's better is an argument you hear all the time. But *better* means different things to different people. Some people think one car is better than another because it's faster or has a bigger engine. Some think another car is better because it's easier on gasoline. *Better* is always a matter of opinion.



MATERIALS PER STUDENT LAB GROUP: None

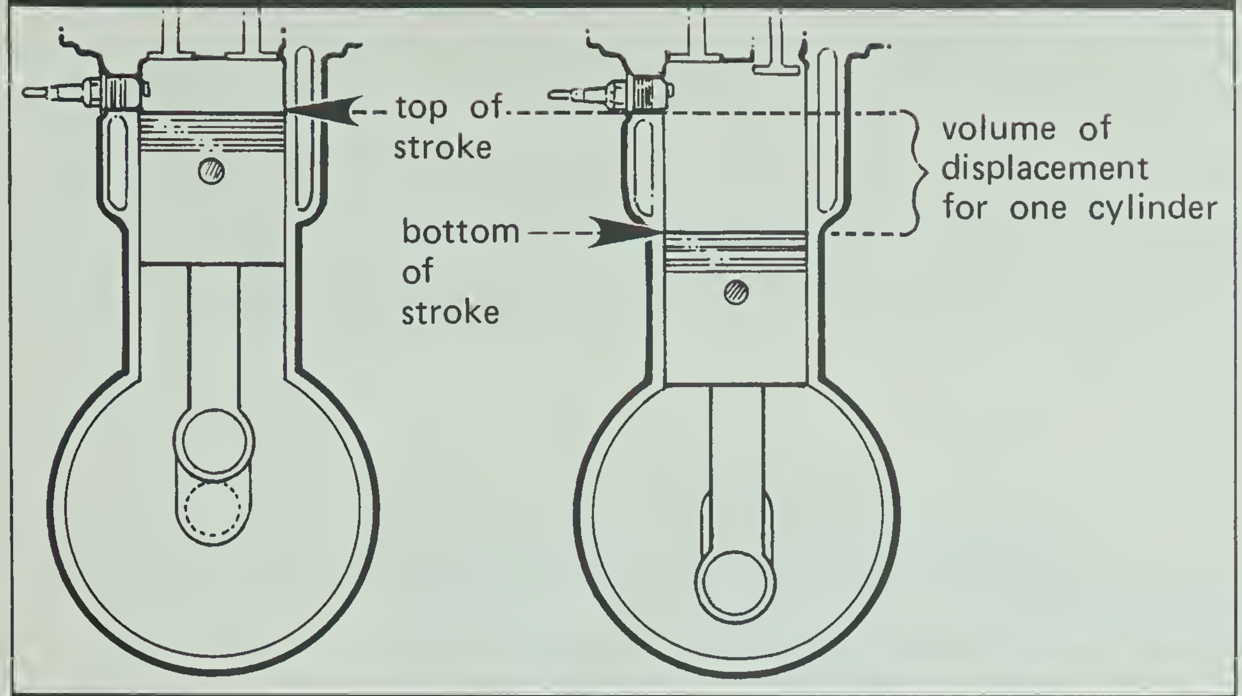
But car owners do like to make comparisons, especially about engines. There are several common ways of comparing engines. Three of these are displacement, power, and compression ratio. Let's look at each of them.

16-1. By height and weight

- 16-1. How do you describe a person's size?

You can talk about a person's size in terms of height and weight. But those terms aren't very useful in describing engines. Materials and design vary too much. A good measure is the number of cylinders. An even better measure is the displacement.

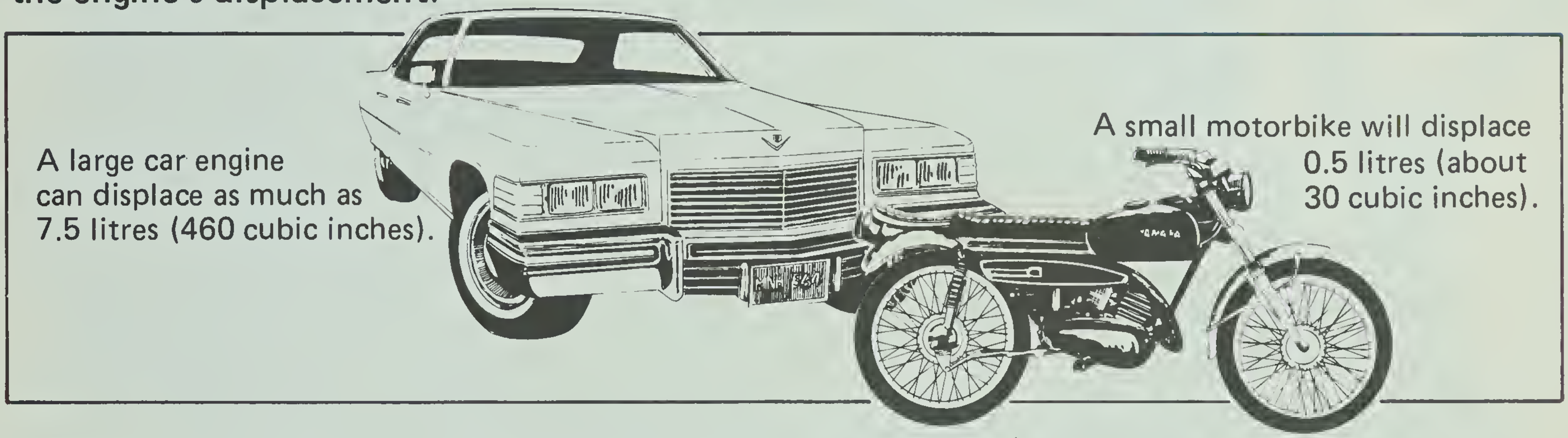
The displacement of a cylinder is the volume through which the piston moves during any stroke.



The engine displacement = the cylinder displacement X the number of cylinders.

☆ **16-2. Displacement is expressed in litres (ℓ). If each piston of an eight-cylinder engine moves through a volume of 0.5 ℓ, what is the engine's displacement?**

16-2. It is 4 ℓ. [Traditional American measure is in cubic inches.]



Engines with larger displacements tend to use more gasoline. They also tend to have more power. Power is the rate of doing work.

The term *horsepower* was originated by James Watt almost two hundred years ago. He found that an average horse could lift 550 pounds of weight one foot every second. He called this *one horsepower*.

The metric system doesn't use the unit of power that Watt used. Instead, it uses a unit named after him – the watt. You probably have used the watt and the kilowatt (1000 watts) for electrical power. The same units are used for all kinds of power in the metric system.

One horsepower equals 746 watts. In other words, one horsepower equals about 3/4 kilowatt (kW).

16-3. 180 kW

• 16-3. A car engine is rated to give 240 hp. What is this power in kilowatts?

There are several ways of rating an engine's power. When engines are being compared, the same standard should be applied to all of them. Figure 16-1 below shows the three main kinds of power rating.

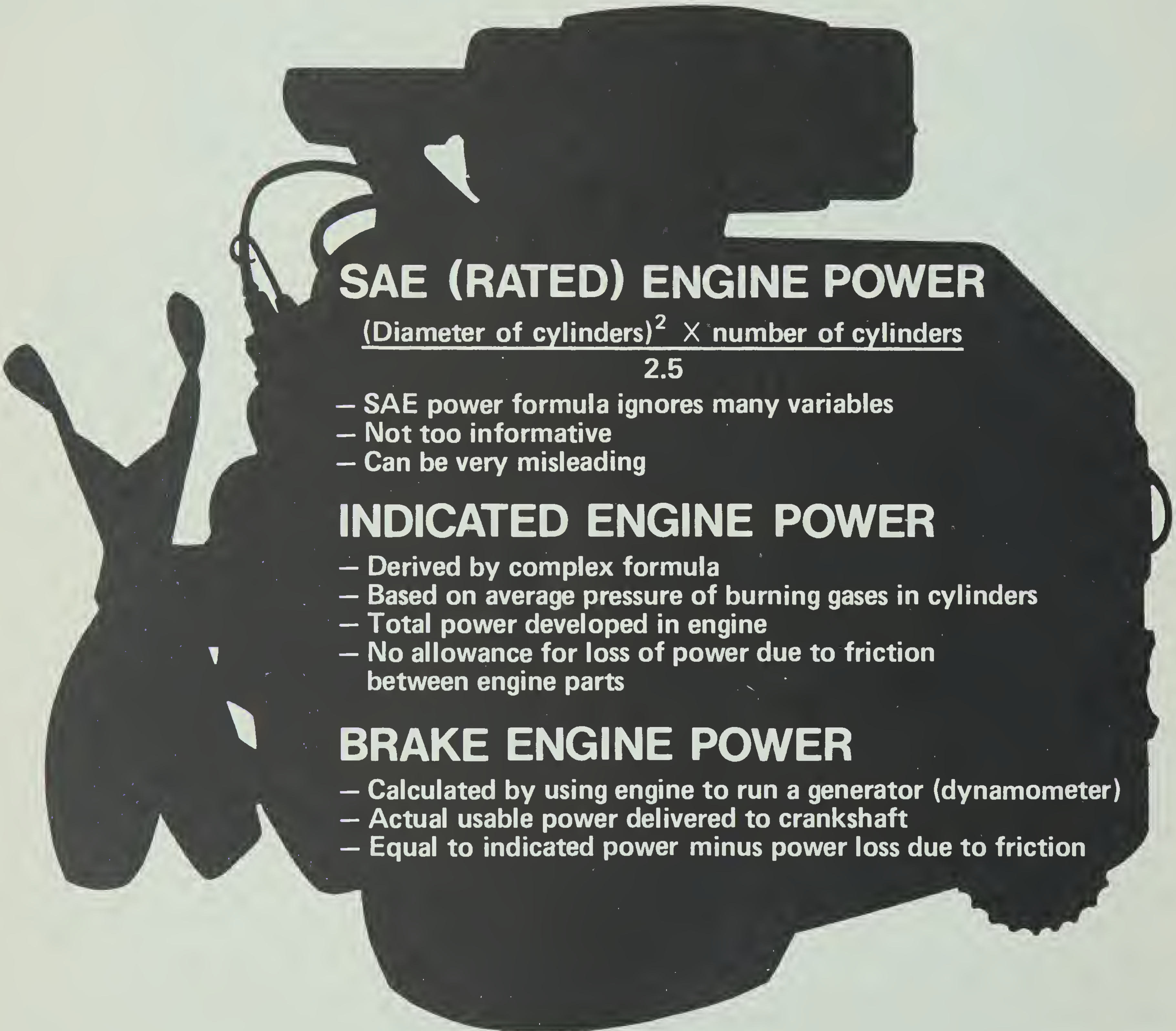


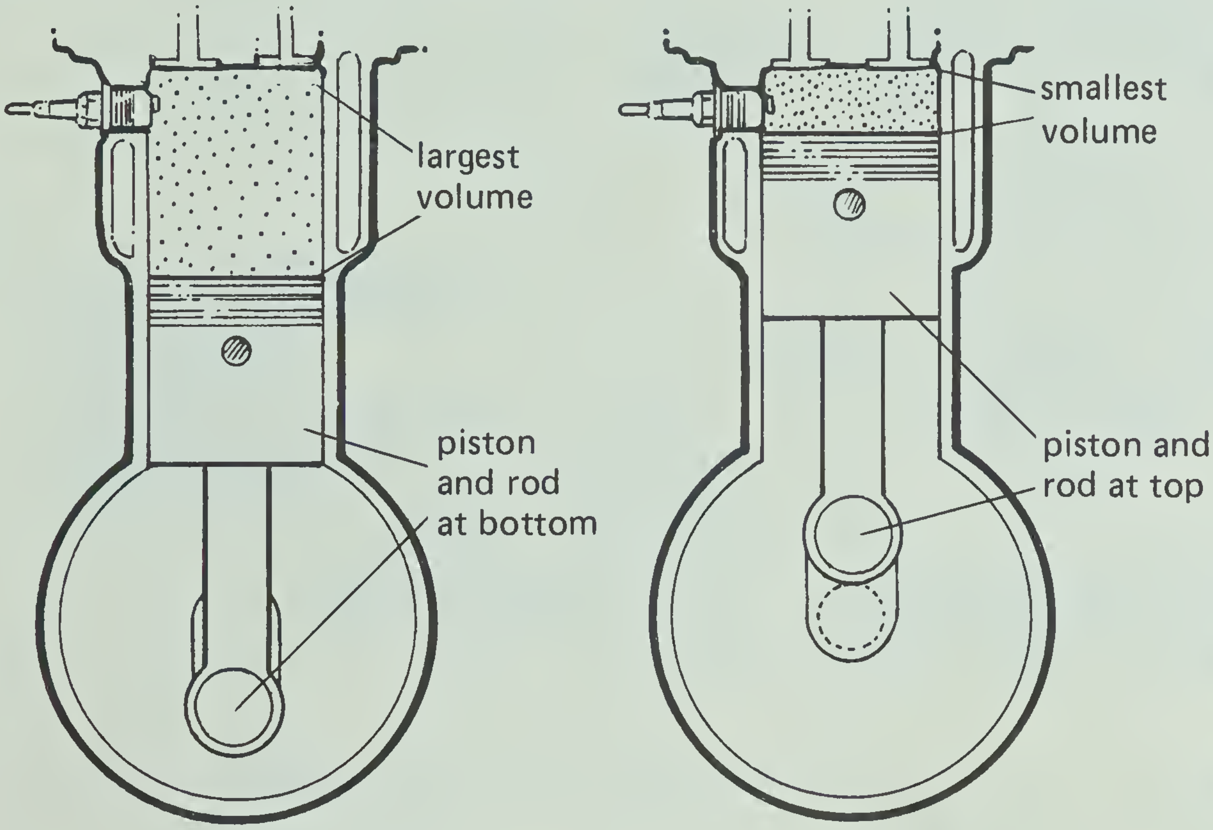
Figure 16-1

☆ **16-4. Which would be greater for a particular engine — its indicated power or its brake power? Why?**

16-4. Its indicated power would be greater. It doesn't take into account the friction between engine parts.

Advertisements for cars usually describe horsepower calculated as indicated power. Sometimes, though, the letters *bhp* follow the power number. *Bhp* means *brake horsepower*. If you compare two engines, be sure to use a single standard. It's worth remembering, too, that more powerful engines burn more gas.

A third measure of engine performance is compression ratio. It tells you how much the piston compresses (squeezes) the air—fuel mixture before ignition.

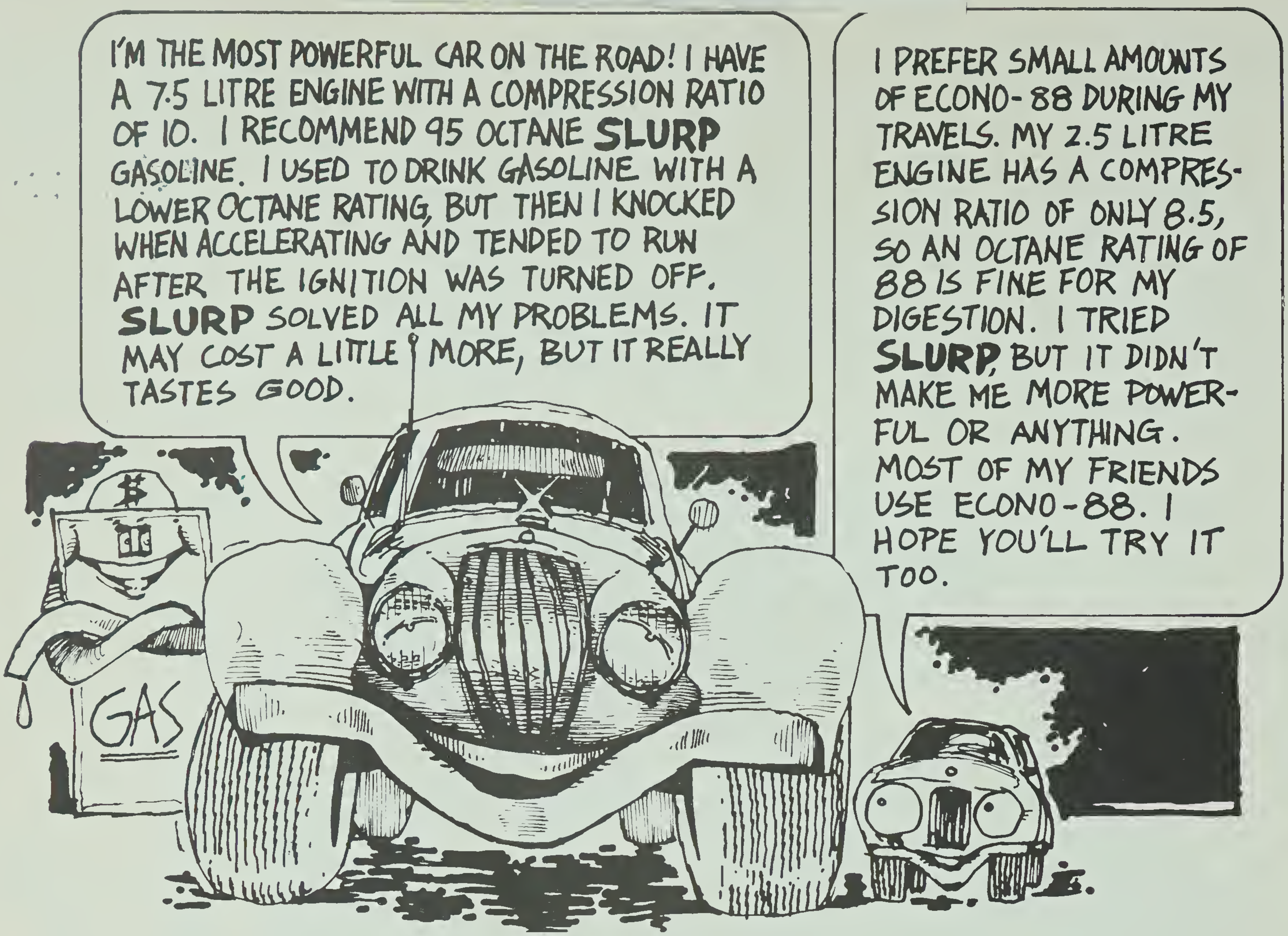


$$\text{COMPRESSION RATIO} = \frac{\text{LARGEST VOLUME}}{\text{SMALLEST VOLUME}}$$

Compression ratios in unmodified engines vary from about 7.5 to 10.5. The most common is 8.5. That means the volume of the air—fuel mixture at the end of the intake stroke is eight and a half times greater than it is at the end of the compression stroke. High-compression engines perform well. They provide more power and burn less gasoline than lower-compression engines of the same displacement.

But a high-compression engine also has a greater tendency to knock. To run well, it needs a gasoline with a higher octane rating. The higher a gasoline's octane rating, the more it resists knocking. And the more it costs!

Engine knock occurs when the end gasoline ignites before the flame front from the spark reaches it. Raising the compression raises the gasoline temperature. Lower octane fuel can reach ignition temperature just by compression and radiation.



16-5. The engine knocks. The engine runs after the ignition is cut off.

• 16-5. What are two signs that a car is using gasoline with too low an octane rating?

16-6. Money is wasted.

• 16-6. What are the results of using a gasoline with an octane rating that is higher than necessary?

Octane ratings can be raised by additional refining of the gasoline or by putting in additives such as tetraethyllead. Refining costs more than adding lead does. Thus, unleaded gasoline costs more than leaded gasoline with the same octane rating. However, the antipollution devices on the newest cars demand unleaded fuel.

16-7. A3, B1, C2

☆ **16-7. Match each performance term on the left with the term of quantity on the right.**

Performance Term	Quantity
A. Displacement	1. 250 bhp
B. Power	2. 9.5
C. Compression ratio	3. 2.5 ℓ

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